IDOE

International Decade of Ocean Exploration

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Program Description

International Decade of Ocean Exploration

Office for the International
Decade of Ocean Exploration

National Science Foundation
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Contents

Preface

... The moisture and varying temperature of the land depends largely upon the positions of the currents in the ocean, and it is thought that when we know the laws of the latter we will, with the aid of meteorology, be able to say to the farmers hundreds of miles distant from the sea, 'you will have an abnormal amount of rain during next summer,' or 'the winter will be cold and clear,' and by these predictions they can plant a crop to suit the circumstances or provide an unusual amount of food for their stock. ... From a study of these great forces, then, we derive our greatest benefits, and any amount of well-directed effort to gain a complete mastery of their laws will revert directly to the good of the human race.

Lt. John E. Pillsbury, 1891
from *The Gulf Stream*

In many respects the history of the evolution of the nature and extent of oceanographic research correlates with the diversity and intensity of man's use of the sea and its resources. As early as 500 B.C. the Phoenicians and other ancient mariners plying the Mediterranean Sea for commerce and conquest, brought forth an early form of oceanographic report, noting not only coastal landmarks and topography, but distances in sailing times, prevailing winds, critical depths, severe currents and, occasionally, bottom conditions. The rising volume of North Atlantic traffic in the last half of the 18th Century inspired and enabled whaler Timothy Folger and statesman Benjamin Franklin each to delineate the Gulf Stream, including seawater temperature tables designed to tell sailing captains if they were in or out of the Stream. The rise of the American Navy and the extension of regular clipper ship schedules to all parts of the world caused Matthew Fontaine Maury in 1855 to publish his "Physical Geography of the Sea" which described ocean winds and currents over major trade routes. To this point in history, however, with the exception of Charles Darwin's cruise aboard *H.M.S. Beagle*, ocean expeditions for pure research were small in number, infrequent and often poorly funded.

Two developments leading to a whole new use of the sea and lending practical importance to the ocean's third dimension were Samuel F. B. Morse's invention in the 1830's of the telegraph and the discovery of gutta-percha in the 1840's as a reliable coating for undersea cables. Suddenly there was a real need to know the ocean's great depths and contours. This need to look beneath the waves intensified man's curiosity about other deep sea phenomena as well. Was there, for example, life in the great depths, or was there a depth limit, an azoic zone in which no life could exist? What were the temperatures of the depths? . . . the currents, if any?

An almost direct cause-and-effect sequence of events can be established leading from the development of undersea telegraphy to the sailing of *H.M.S. Challenger* on its world-famous three-and-a-half year voyage of discovery in 1872 and the countless expeditions that ensued through the balance of the 19th and the early part of the 20th Century.

In the period that followed, the military submarine came into being, raising a host of new and different questions about the ocean. World fisheries expanded from a largely coastal, unmechanized, limited-catch activity to its present state where great industrial fishing expeditions roam the world catching with such intensity that whole stocks are threatened with extinction, and conflicts over access occur among nations. The industrial and economic activities of man ashore have increased to a point where wastes released to the ocean, once minor and incidental, now have the potential for major impact with, again, conflicts. The rapid draw-down of mineral and fuel re-

sources ashore coincident with the realization that vast resources may be found beneath both the shallow and deep sea constitutes another intensive use of the sea, another source of international conflict. The science of meteorology and the demands of modern society on it have advanced to the point where weather forecasters need to know the influence of the ocean on weather in discrete, real-time terms. These and other uses each have required more knowledge. The development of such knowledge illuminates new uses and resources of the sea which, in turn, create a new demand for knowledge.

Thus, the uses and the users of the sea have increased and continue to increase in both diversity and intensity. A once inexhaustible resource has quite suddenly acquired limits, and "use of the sea" becomes increasingly synonymous with "abuse of the sea." Free access to, and the laissez-faire taking of, oceanic resources is being forced to give way to allocation and management. The need to know the ocean, its processes and resources in greater detail and in quantitative as well as qualitative terms, therefore, is dictated in large measure by the need both domestically and internationally to make important social, economic and political decisions relating to management and access. Hypothesis, speculation and unsupported opinion lead to emotional confrontations. Knowledge, broadly acquired and soundly based, provides a factual foundation on which intelligent and acceptable rules and institutions can be built. Thus, only through a thorough understanding of the laws and processes at work in the ocean it is possible to hope, as Pillsbury postulated, that the fruits of research efforts will "revert directly to the good of the human race."

Feenan D. Jennings, *Head*
Office for the International Decade
of Ocean Exploration

U.S. PARTICIPATION IN THE INTERNATIONAL DECADE OF OCEAN EXPLORATION

The mid-1960's was a critical turning point in marine activities. In the United States the 1966 enactment of the Marine Resources and Engineering Development Act and creation of the national Sea Grant College Program reflected the growing concern for man's use and protection of the marine environment. That same year the United Nations General Assembly asked the Secretary General to survey the marine science and technology activities both of member States and those of intergovernmental and nongovernmental international organizations, and to compile proposals to bring about the most effective arrangements for an expanded program of international cooperation.

Common to these actions was the acknowledgment that nearly all the issues relating to the seas transcend national boundaries. President Lyndon B. Johnson captured this feeling in his remarks commissioning the research ship *Oceanographer* in July 1966. He observed that:

> Truly great accomplishments in oceanography will require the cooperation of all the maritime nations of the world. And so . . . I send our voice out . . . calling for such cooperation, requesting it, and urging it. . . . We greatly welcome . . . international participation. Because under no circumstances, we believe, must we ever allow the prospects of rich harvests and mineral wealth to create a new form of colonial competition among the maritime nations. We must be careful to avoid a race to grab and to hold the lands under the high seas. We must ensure that the deep seas and the ocean bottoms are, and remain, the legacy of all human beings.

In March 1968 the President endorsed the concept of an International Decade of Ocean Exploration. He stated:

> The task of exploring the ocean's depth for its potential wealth—food, minerals, resources—is as vast as the seas themselves. No one nation can undertake that task alone. As we have learned from prior ventures in ocean exploration, cooperation is the only answer.
>
> *I have instructed the Secretary of State to consult with other nations on the steps that could be taken to launch an historic and unprecedented adventure—an International Decade of Ocean Exploration for the 1970's.*[1]

Two months later the Intergovernmental Oceanographic Commission (IOC) adopted a formal recommendation supporting the Decade idea and went on to endorse "the concept of an expanded, accelerated, long-term and sustained program of exploration of the oceans and their resources including international programs, planned and coordinated on a world-wide basis." Further endorsements came from the United Nations General Assembly. In December 1968 the United Nations endorsed the idea of a coordinated, long-term program of oceanographic research and formally welcomed the proposed Decade as an important part of this effort. General Assembly Resolution 2467 D (XXIII) endorsed "the concept of an international decade of ocean exploration to be undertaken within the frame-

[1] Special Message to the Congress on Conservation: "To Renew a Nation," March 8, 1968.

work of a long-term programme of research and exploration . . .," and further invited member states "to formulate proposals for national and international scientific programmes and agreed activities to be undertaken during the international decade of ocean exploration with due regard to the interests of developing countries, to transmit these proposals to the United Nations Educational, Scientific, and Cultural Organization for the Intergovernmental Oceanographic Commission in time to begin the decade in 1970, and to embark on such activities as soon as practicable."

At its Sixth Session in September 1969 the Intergovernmental Oceanographic Commission defined the purpose of the expanded program to be: "To increase knowledge of the ocean, its contents and the contents of its subsoil, and its interfaces with the land, the atmosphere, and the ocean floor and to improve understanding of processes operating in or affecting the marine environment, with the goal of enhanced utilization of the ocean and its resources for the benefit of mankind. . . ." At the same time the IOC established a Group of Experts on Long-Term Scientific Policy and Planning who were "to develop the scope and content of the long-term and expanded programmes of oceanographic research of which the International Decade of Ocean Exploration is an important element."

The U.S. National Council on Marine Resources and Engineering Development then invited the National Academy of Sciences and National Academy of Engineering to prepare detailed recommendations for the United States contribution to the Decade. Distinguished scientists and engineers from the academic, industrial and governmental communities examined the full range of questions related to this unprecedented effort. Attention focused on priorities among the scientific and engineering goals, the capabilities necessary to realize them and the products and benefits to mankind anticipated from implementation of the Decade idea. In May 1969 the Academies jointly reported their conclusions.[2]

The guiding premise of the International Decade concept was that sustained international planning and coordination would target on the most promising geographic areas and lines of scientific inquiry, set priorities and agree on the sharing and distribution of effort. The results of this work would be published freely and promptly for the benefit of everyone. There was to be strong insistence on standardized data collection and dissemination, expanded activity by a large number of nations and greater coordination among the international organizations concerned with the oceans. In short, the Decade was to be a period of "intensified collaborative planning among nations and expansion of exploration capabilities by individual nations, followed by execution of national and international programs of oceanic research and resource exploration so as to assemble a far more comprehensive knowledge of the sea in a reasonably short time."[3] The anticipated success of the effort hinges largely on the "extent to which various nations contribute their particular expertise and capabilities, assume a share of responsibility for the program, develop their manpower and facilities and disseminate to others the results of scientific and other discoveries."[4]

As a major part of President Richard M. Nixon's program in marine science, Vice-President Spiro T. Agnew announced on October 19, 1969, the initial U.S. plans for participation in the International Decade of Ocean Exploration. Several weeks later the Vice-President, in his capacity as Chairman of the National Council on Marine Resources and Engineering Development, assigned responsibility for the planning, management and funding of United States IDOE activities to the National Science Foundation. In assigning Decade responsibility to the Foundation, the Vice-President set out the following goals:

- Preserve the ocean environment by accelerating scientific observations of the natural state of the ocean and its interactions with the coastal margin—to provide a basis for (a) assessing and predicting man-induced and natural modifications of the character of the oceans;

[2] *An Oceanic Quest, the International Decade of Ocean Exploration*, National Academy of Sciences and National Academy of Engineering, Washington, D. C., 1969.

[3] *Marine Science Affairs—A Year of Broadened Participation.* The Third Report of the President to the Congress on Marine Resources and Engineering Development, January 1969, p. 125.

[4] *ibid.*, p. 126.

(b) identifying damaging or irreversible effects of waste disposal at sea; and (c) comprehending the interaction of various levels of marine life to permit steps to prevent depletion or extinction of valuable species as a result of man's activities;

- Improve environmental forecasting to help reduce hazards to life and property and permit more efficient use of marine resources—by improving physical and mathematical models of the ocean and atmosphere which will provide the basis for increased accuracy, timeliness, and geographic precision of environmental forecasts;
- Expand seabed assessment activities to permit better management—domestically and internationally—of marine mineral exploration and exploitation by acquiring needed knowledge of seabed topography, structure, physical and dynamic properties, and resource potential, and to assist industry in planning more detailed investigations;
- Develop an ocean monitoring system to facilitate prediction of oceanographic and atmospheric conditions—through design and deployment of oceanographic data buoys and other remote sensing platforms;
- Improve worldwide data exchange through modernizing and standardizing national and international marine data collection, processing, and distribution; and
- Accelerate Decade planning to increase opportunities for international sharing of responsibilities and costs for ocean exploration, and to assure better use of limited exploration capabilities.

Shortly after receiving the Vice-President's charge, the National Science Foundation set up the Office for the International Decade of Ocean Exploration and began to define the United States program. In the first year of the Decade's existence, three areas were chosen for priority attention: (1) environmental quality; (2) environmental forecasting; and (3) seabed assessment. In 1971 living resources was added as a fourth program area. The remainder of this report describes the status, accomplishments and plans for the projects within each of these major program areas, as well as the technological and international aspects that are integral parts of the IDOE concept.

ENVIRONMENTAL QUALITY

Over the past three decades human activities have had a growing impact on the quality of the marine environment. The introduction of biologically active chemicals into the oceans has made it necessary to determine the extent to which these pollutants threaten to alter the natural state of the oceans.

In August 1971 an international group of scientists actively engaged in environmental research met to consider critical areas in environmental quality research and to recommend research priorities. They emphasized the need to: (1) identify major pollutants and their probable sources and rates of release; (2) delineate processes affecting the dispersal of these pollutants; (3) understand the geochemical and biological transfers of each element or compound in the ocean; (4) determine the effects of pollutants on organisms and their life processes; and (5) determine the sites where pollutants are finally deposited in the ocean.[1]

These recommendations, plus those from subsequent workshops, have provided the basis for the IDOE program in Environmental Quality. Its major research areas include baseline data collection, studies of the transfer and effects of pollutants and the use of geochemical analysis in the study of diffusion, mixing and large scale ocean circulation.

PROGRAM:

BASELINE DATA RESEARCH

In 1971-72, regional baseline data acquisition projects funded by NSF/IDOE were conducted in the Atlantic and Pacific Oceans, the Gulf of Mexico, and the Caribbean. Quantitative results were obtained on the occurrence and distribution of trace metals, chlorinated hydrocarbons (DDT, DDE, TDE), polychlorinated biphenyls (PCB) and petroleum in the water, biota and sediment. A deliberate effort was made to use reference samples and to interchange replicate samples frequently among participating laboratories in the United States and United Kingdom. Throughout the study analytical data were constantly interchanged. The extensive sampling provided sufficient material to establish approximate baseline levels for the pollutants measured.

Baseline Conference

The participants in the baseline data acquisition projects and other environmental scientists—60 university, industrial and government experts from both the U.S. and abroad—met at Brookhaven National Laboratory in May 1972 to assess the data, evaluate the program and make recommendations for future research.

Prior to this Conference an 800-page compilation of data resulting from the baseline data acquisition projects was studied by all the participants to ensure a thoroughly critical review. The Conference was extremely valuable in describing program deficiencies and in stimulating new insights into research projects.

Within a week after the Conference a report summarizing the results and recommendations for future marine environmental research was published, and distributed shortly thereafter at the UN Conference on The Human Environment held in Stockholm.[2] The following general position was taken by the participants:

RECOMMENDATION

The participants of the National Science Foundation's IDOE Baseline Confer-

[1] *Marine Environmental Quality*, National Academy of Sciences, Washington, D. C., 1971.

[2] *Baseline Studies of Pollutants in the Marine Environment and Research Recommendations, The IDOE Baseline Conference, May 24-26, 1972*, New York 1972.

ence unanimously agree that the highest priorities should be given to determining the impact of pollutants (e.g., synthetic organic chemicals, petroleum, and metals) on the nearshore marine environment. We feel that this is the concern of national or regional authorities.

The readily identifiable contamination in the open ocean by synthetic halogenated hydrocarbons (such as PCB and DDT and their metabolites) and petroleum hydrocarbons potentially constitute a problem of global concern. We therefore recommend: That a continuing research program to determine inputs, dispersal paths and present levels of the synthetic halogenated hydrocarbons and of petroleum hydrocarbons in representative plants and animals of coastal and open ocean zones be immediately initiated with the objectives of evaluating hazards to living processes and of defining sources of these materials. Simultaneously and with high priority, research should be expanded in biological laboratories to evaluate the impacts of existing levels of these substances upon living organisms. Until this is done, every effort should be directed toward restricting discharges to the marine environment.

Lead Analysis Workshop

As a result of the Brookhaven Conference discussions on the determination of lead levels in seawater, a group of investigators interested in heavy metal determinations undertook a careful comparison of lead analysis methods. The purpose is to ascertain that technique which is rapid and inexpensive, but which, nevertheless, gives the desired accuracy and sensitivity. Isotope dilution mass spectrometry, although slow and expensive, has sufficient sensitivity and accuracy to provide standardized samples of seawater suitable for evaluating the more rapid and inexpensive atomic absorption and anodic stripping techniques. The final evaluation of techniques is taking place at the California Institute of Technology following analysis by the investigators of standard samples in their own laboratory.

Important objectives of these studies are (a) to establish the minimum size of water sample needed to overcome errors due to sensitivity and contamination, and (b) to describe necessary precautions for reducing contamination effects during shipboard collection and analytical treatment.

The program consists of three phases:

(1) analysis of water samples by participating laboratories;

(2) meeting to exchange views and formulate recommendations; and

(3) analysis of additional standards, if necessary, and the summarization of program results.

Projects of this type are vital to investigators concerned with the levels of pollutants in the ocean, and it may be desirable to arrange similar studies for measuring other pollutants.

POLLUTANT TRANSFER PROCESS RESEARCH

A detailed understanding of mechanisms controlling the rate of pollutant transfer from source to and within the ocean is necessary for predicting pollutant distribution in the marine environment, for assessing whether the oceans are becoming measurably polluted, and ultimately for indicating rates at which such pollutants may be released safely to the environment. Before meaningful experiments can be conducted on the effects of pollutants, it is necessary to know if and how particular pollutants are taken up and concentrated by organisms. Likewise, if the final deposition of pollutants is to be determined, one must understand the types and rates of chemical transformations that occur as the pollutants are transferred into and among water, organisms and sediments.

The IDOE Pollutant Transfer Process Research Program is designed to contribute to the solution of these problems. The research projects in this area are summarized in Table 1. Research on riverine and atmospheric introduction of pollutants (heavy metals and synthetic organic compounds) may help to answer the basic question of whether the ocean is being measurably polluted. The quantities and forms of heavy metals, halogenated hydrocarbons and petroleum hydrocarbons are determined at the sea surface and in the coastal regions where they enter the

marine environment. Particular attention is given to the concentration and dispersion of pollutants at the air-sea interface, injection of pollutants through estuaries to continental shelf waters, pollutant emplacement in sediments and the chemical forms of each pollutant.

Chemical Studies

These studies involve investigation of the alteration of the physical and chemical properties of pollutants. The studies are carried out as integral parts of research projects concerning the dispersion of pollutants in the marine environment and the uptake of pollutants by organisms. Chemical problems being considered are: (1) the form of heavy metals (organic complex, adsorbed, detrital); (2) the types of PCB (several types have been released into the environment); (3) the nature of the equilibrium between pollutants in water and in the lipid fraction of organisms; (4) the weathering of tar balls and resulting changes in their chemical compositions; and (5) the changing chemical nature of pollutants as they enter different aquatic environments.

Table 1
POLLUTANT TRANSFER PROCESS
RESEARCH PROGRAM

Material	Heavy metals	Halogenated hydrocarbons	Petroleum
Process	Number of Projects		
Atmospheric	2	2	1
Riverine	2	1	—
Chemical	2	3	2
Biological	2	4	1
Geological	2	—	—

Biological Studies

The biological research programs are designed to quantify the mechanisms of pollutant uptake by organisms and the means of pollutant transfer through the food web. A variety of questions needs to be answered. Are pollutants taken up directly from the water, passively absorbed by organisms or ingested with their food? Should high concentrations of heavy metals in higher predatory organisms be ascribed to food-chain amplification or to absorption over their longer life spans? Do pollutant concentrations in organisms equilibrate with their aquatic surroundings? What is the significance of different levels of pollutant residues in organisms? Do they reflect ambient concentrations or previous short-term exposure to high pollutant concentrations? What are the half-life residence times of various pollutant forms in different organisms? Such information is especially important for interpreting those studies in which selected species are monitored for levels and significance of environmental pollution.

Goals

The goals of the transfer process research program are: (1) to determine important transfer mechanisms; (2) to identify major environmental factors that affect the transfer processes; and (3) to develop the principles governing transfer.

EFFECTS OF POLLUTANTS ON MARINE ORGANISMS

The baseline and transfer studies provide the foundation for investigations designed to determine the extent to which pollutants have an adverse effect on marine life. The pollutant effects research projects portion of the Environmental Quality Program involve three distinct levels of marine life: cell-free enzymes and bacteria, whole organisms (zooplankton, microalgae and higher forms) and complete communities. Studies at any level are guided by three considerations: (1) concentrations of pollutants should be at or near the concentrations known to be present in marine waters and sediments; (2) biological limits used for detection of pollutant effects should be something other than acute toxicity levels; and (3) studies should include both laboratory and field phases. All investigators have agreed to use pollutants (petroleum, PCBs and others) from a common source so that results may be more directly comparable and duplication of the analytical work necessary to characterize pollutants may be avoided. Research projects were initiated in 1973 dealing with the biological effects on marine organisms of trace metals, petroleum, halogenated hydrocarbons, and other synthetic organic compounds. These are shown in Table 2.

Biochemical Studies

Biochemical studies concentrate on the effect of pollutants on bacteria and key enzymes and enzyme systems. If successful the techniques used to study the effects of petroleum compounds on the rates of reaction of these enzymes in a cell-free assay could be extended to other pollutants.

Table 2
BIOLOGICAL EFFECTS PROGRAM

	Contaminant		
	Halogenated hydrocarbons	Petroleum	Trace metals
Biological Material	Number of Projects		
Cell-free enzymes	—	1	—
Bacteria	1	1	—
Phytoplankton	2	1	—
Zooplankton	1	1	—
Higher organisms	2 *	2	—
Communities	project being reviewed		—

* Pilot study of biological effects of phthalates in one project

Whole Organism Studies

The effects of pollutants on photosynthetic microalgae will be determined by measurements of growth, respiration and photosynthetic rates. If severe effects are observed, morphological changes will be sought using light and electron microscopy. Both pure and mixed cultures will be used in these studies. The short generation time of microalgae makes them well suited for short-term experiments.

In the case of zooplankton and higher organisms, a much longer generation time dictates that biological parameters other than growth and reproductive rates must be used to measure pollutant effects. Metabolic rate, determined by oxygen consumption, is being used with animals at several trophic levels. Other parameters being investigated include filtering and ventilation rates, lethal temperature limits, simple behavior and genetic structure changes as measured by electrophoresis of protein molecules.

Community Studies

The community studies require living systems that are less than complete compared to natural ecosystems but which are still enough like the natural system to provide valid answers about pollutant effects. Research on the effects of chemical pollutants on ocean ecosystems is being carried out by scientists from several U.S. and Canadian institutions in the Controlled Ecosystem Pollution Experiment (CEPEX).

In this project natural marine communities are maintained in large, flexible plastic cylinders which are open to the atmosphere and closed at the bottom (Figure 1). In the experiment the contents of one enclosure are altered by adding chemical pollutants while a second functions as a control. The response of specific trophic levels to the chemical perturbations will be assessed and the changes compared to those taking place in the control enclosures which are maintained under conditions as close as possible to the natural environment. These experiments are interdisciplinary, requiring cooperative research

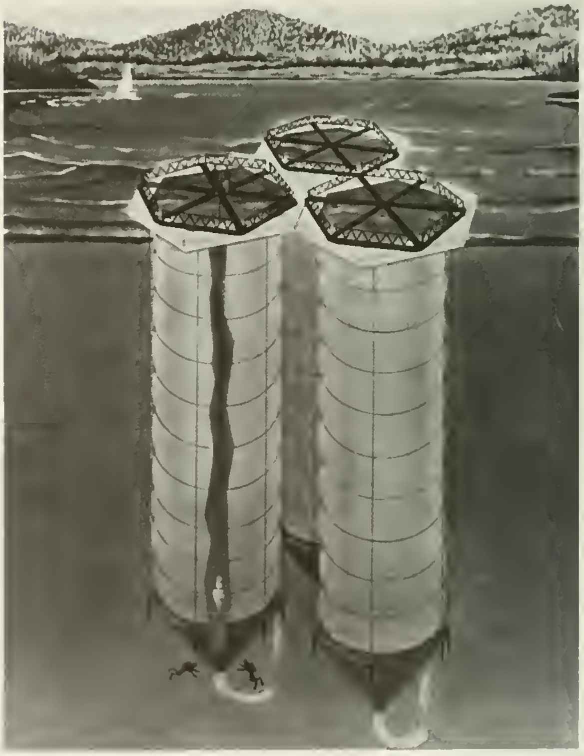


Figure 1

by chemists, microbiologists, botanists, zoologists and mathematical modelers.

The first CEPEX experiment is being carried out at Saanich Inlet, Vancouver, British Columbia, Canada. During the summer of 1973 three prototype enclosures (2x10 meters) were built and tested in the Inlet. (Fig. 2.) At the same time researchers surveyed the pollutant baseline levels and the natural plankton populations in the experimental areas. If these pilot experiments confirm present expectations, full-scale enclosures (10x30 meters) will be built the second year.

Figure 2

Goals

A primary goal of the biological effects projects is to determine whether open ocean organisms are more sensitive to pollutants than the inshore forms. If they are, the fact that they receive less pollution may be cancelled by their greater sensitivity. If a given trophic level is more affected by pollutants than others, then one would expect that level in the ocean food chain to be the critical link in the biological response of the ocean to pollution. Recognition of these types of relationships will contribute to the intelligent management of ocean resources.

GEOCHEMICAL OCEAN SECTIONS STUDY (GEOSECS)

The Geochemical Ocean Sections Study (GEOSECS) is significant to both the Environmental Quality and the Environmental Prediction Programs. The multi-year project, designed to provide global baseline data and to further understanding of physical oceanic processes, involves geochemists from 15 U.S. universities and participation from Canada, France, the Federal Republic of Germany, India, Italy and Japan. Major portions of the U.S. program are based at the Woods Hole Oceanographic Institution and the Scripps Institution of Oceanography.

Man's exploitation and conservative management of planetary resources depend on detailed understanding of oceanic processes including stirring and mixing in the deep sea, the interchange of energy and material between deep and surface water and the exchange of energy and material between the water and the atmosphere.

Background

The ocean appears to resemble a great convective cell in which the upper layers are heated by the sun and stirred by wind-driven waves and currents. Cold water sinking in the polar regions where surface waters lose their heat and increase in salinity through ice formation seems to provide the mechanism which drives this circulation. New bottom water, thus formed, flows as abyssal currents to the deep basins of the oceans. Although two areas are known where abyssal currents originate—namely, the North Atlantic Ocean and the Weddell Sea in the Antarctic region of the South Atlantic—the rates at which such water masses form, the nature of their subsequent sub-surface flow within the dif-

ferent oceans and whether other sources exist are not known. GEOSECS research contributes substantially to the understanding of these processes.

Although a crude idea exists of the average effective speed of chemical constituent diffusion processes, little is known of the vertical, horizontal or time-dependent variations, or of the source of energy that drives the turbulence. Radionuclides such as strontium, cesium, tritium and man-produced carbon-14, recently introduced to the surface waters as fallout, are measured by the GEOSECS scientists. They are used to deduce the rates of downward mixing from the surface to intermediate depths, thus determining (quantitatively) the rates of turbulent diffusion and downwelling in various oceanic situations.

Interpretation of radioisotope tracer data in relation to the rate of vertical mixing requires exact knowledge of the concentrations of the corresponding stable isotopes. For example, the release in deep water of $C^{14}O_2$ by the decay and sinking of biological particles is correlated with the release of stable CO_2 which can be estimated from measurement of dissolved total CO_2, alkalinity and pH, or any two species within the oceanic carbonate system. Measurements of the concentrations of the natural radioactive isotopes radium-226, silicon-32 and cosmic-ray-produced carbon-14 in the deep and bottom waters of the ocean will improve knowledge of advection and turbulent diffusion. These convenient nuclear clocks are being used to determine the age of water masses in much the same way that carbon-14 is used to measure the age of solid objects. The potential of these new methods for studying the sea has only begun to be realized.

GEOSECS scientists are making detailed measurements of oceanic constituents at all depths along north-south sections from the Arctic to the Antarctic, to provide, for the first time, a set of physical and chemical data measured on the same water samples. In addition to establishing geochemical baselines, these data will provide input for quantitative studies of oceanic mixing and for descriptive models of ocean circulation.

Sampling Plan

The U.S. portion of the project calls for the occupation of oceanographic stations along survey tracks which follow the approximate trajectories of the bottom water currents in the Atlantic and Pacific Oceans. The U.S. schedule of cruises includes the Woods Hole Oceanographic Institution's *R/V Knorr* running the Atlantic track during July 1972-April 1973 and Scripps Institution of Oceanography's *R/V Melville* running the Pacific track during August 1973-May 1974 (Figure 3). Cruises by ships of West Germany, Japan and other nations add supplementary sections.

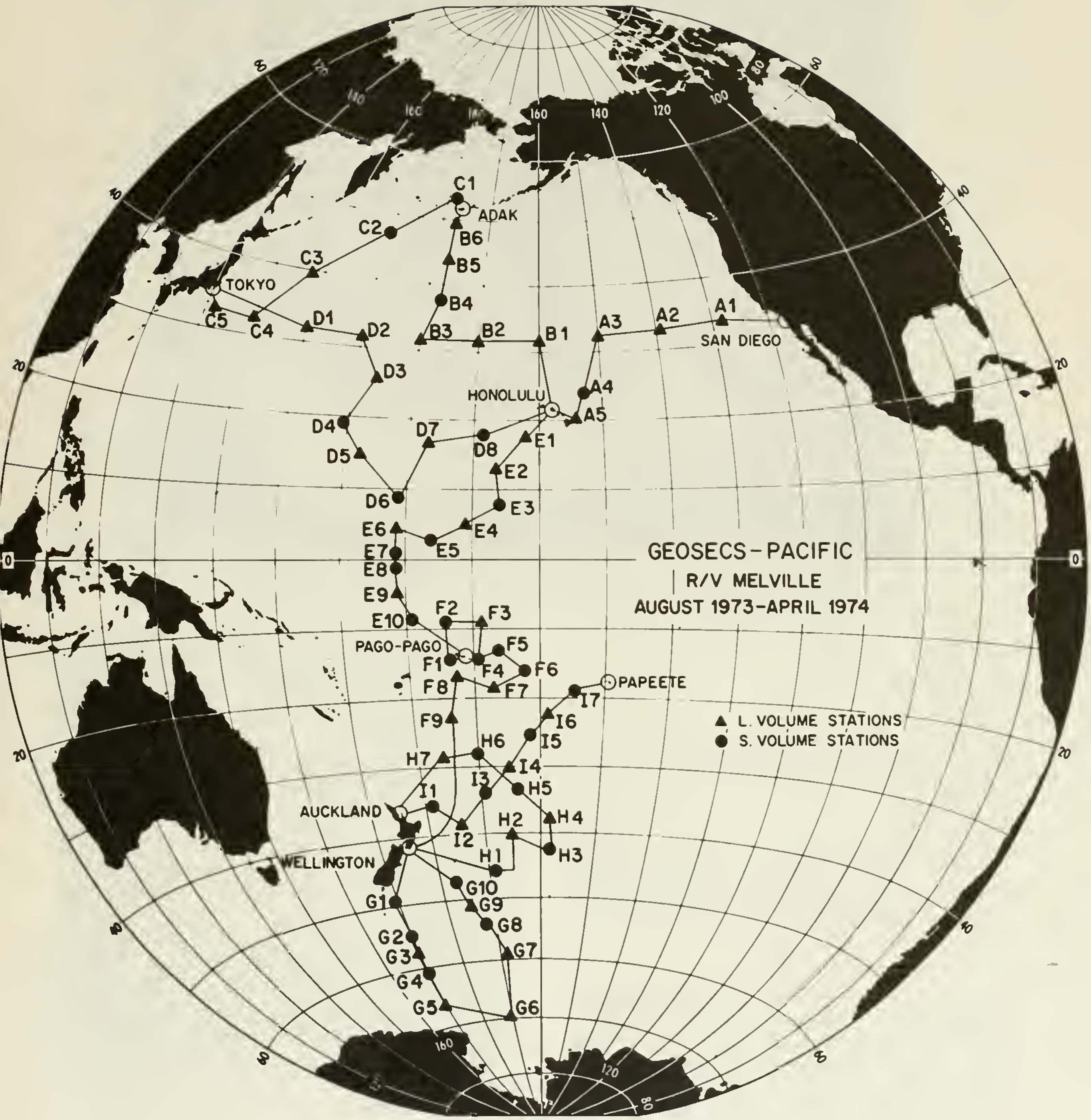
At each U.S. station vertical profiles of 50 samples are taken, and at alternate stations large samples are taken at 16 to 20 depths for measurements of trace constituents and low concentration radioisotopes. The vertical spacing of all these samples is guided by continuous on-station recording of temperature, salinity and dissolved oxygen. Particulate matter is collected at all depths, and dissolved gases are extracted from the sea water for onboard analysis by gas chromatography. Much of the analytical work is done on the ships during the expedition, with the balance to be done in the laboratories of participating geochemists throughout the world. For future work a library of water samples is maintained at Woods Hole.

Shipboard Laboratory Analyses

Since project success depends upon the precise and rapid measurement of several ocean variables automated analytical systems are used aboard ship for many of the routine chemical measurements. All physical and chemical measurements made at sea are fed into the shipboard computer. Data logged from principal and auxiliary sources are brought together in a real-time system to compute final values of all parameters. A large proportion of the data is, therefore, available for evaluation by the Chief Scientist while still on station (Figure 4).

The computer console consists of: Analogue tape recorder for recording signals from the *in situ* package, trouble-shooting equipment, real-time clock, trigger controls for the rosette, cathode ray display units, typewriter terminal, hard copy reproduction unit for printing cathode ray tube displays and an X-Y print plotter.

The following shipboard systems are automated or partially automated and interfaced with the computer: Salinometry, alkalinity-


GEOSECS - PACIFIC
R/V MELVILLE
AUGUST 1973 - APRIL 1974
L. VOLUME STATIONS
S. VOLUME STATIONS
TOKYO
ADAK
HONOLULU
SAN DIEGO
PAGO-PAGO
PAPEETE
AUCKLAND
WELLINGTON
A1
A2
A3
A4
A5
B1
B2
B3
B4
B5
B6
C1
C2
C3
C4
C5
D1
D2
D3
D4
D5
D6
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D8
E1
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F9
G1
G2
G3
G4
G5
G6
G7
G8
G9
G10
H1
H2
H3
H4
H5
H6
H7
I1
I2
I3
I4
I5
I6
I7

Figure 3

Figure 4 Nerve center. Scientists at a computer console aboard the Knorr can request displays of data being collected far below by undersea instruments, displays of analyses from the shipboard labs, or displays of comparison records from other times.

total CO_2 titration, gas chromatography (total CO_2, N_2, Ar), autoanalysis (NO_2-, NO_3-, PO_4---, SiO_2) and Rn^{222}.

Data from the thermosalinograph, atmospheric sensors, ship speed and heading indicators and satellite navigation systems are added continually and automatically to the computer data bank and are available for instant recall.

Salinometry. In the Atlantic, the University of Washington Bridge and Schleicher-Bradshaw salinometers are being used with a precision of $\pm$ .003 parts per mille. Readings from these laboratory salinometers are used to calibrate the salinity-temperature-depth sensor on the bottom package. Presently, two people working full time are required for salinometry, but it is hoped that an automatic laboratory salinometer now available will reduce manpower requirements for this task.

Alkalinity-Total CO_2—Alkalinity-total CO_2 is analyzed by an automatic titrator which is under process control from the computer. The Gran plot method described by Edmond is used to process the data. Precisions of 0.1% are being obtained for alkalinity and 0.2% for CO_2. This is the best precision ever obtained for these parameters.

Argon and Nitrogen—Two chromatographs are used on board ship, one for the analysis of total CO_2 and another for the analysis of dissolved argon and nitrogen. The two chromatographs operate concurrently and are contained in the same enclosure. The total CO_2 gas chromatograph uses a thermal detector, the argon-nitrogen, an ultrasonic detector.

Nutrients—The nutrients (phosphate, silicate, nitrate and nitrite) are measured using a four-channel autoanalyzer calibrated to GEOSECS and Sugami standards. Data from the chart recorder is punched and processed

by the computer. A precision of 0.5% is obtained. Calibration from leg to leg is well-maintained.

Radon—Excess radon gas is measured in both surface and near-bottom profiles at each station. It is extracted from samples by flushing with helium and freezing at liquid nitrogen temperatures. Four extraction systems are in use at all times, and the extraction time is approximately two hours. Following purification to remove water and carbon dioxide, the radon gas is transferred to a counting system consisting of eight scintillation tubes.

All shipboard automatic systems are designed and programmed so that analyses may also be done manually.

In Situ Underwater Measurement

In addition to measurements on board ship from bottle samples, scientists use a newly developed underwater sensor package (Figure 5) which includes: Conductivity-temperature-depth (CTD) sensor; bottom proximity pinger, dissolved oxygen probe, nephelometer and a rosette of 30-liter sampling bottles.

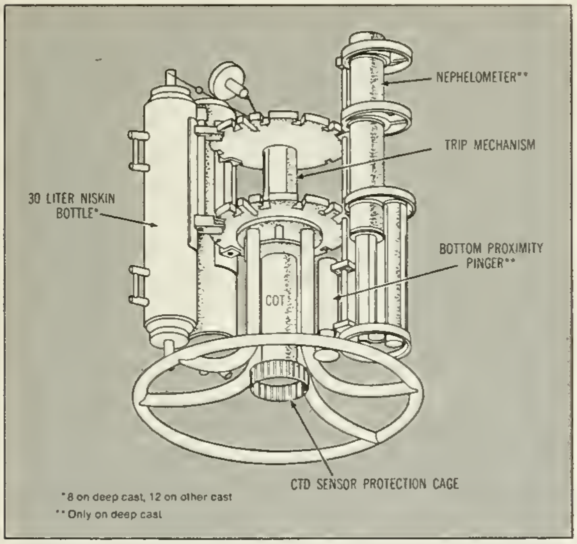


Figure 5 GEOSECS underwater sensor package.

Conductivity-Temperature-Depth. The CTD sensor is an adaptation of one constructed at the Woods Hole Oceanographic Institution. The instrument, originally intended for microstructure work, has a high rate of data accumulation. The CTD profile is fed to the shipboard computer.

Bottom Proximity. Bottom proximity is detected by a 12 KHz pinger mounted on the rosette and monitored with a precision depth recorder on board the ship.

Dissolved Oxygen. An oxygen sensor that works below 2,000 meters is not available commercially. In an effort to overcome this limitation, investigations were conducted on the various sensors available. Results show that the membrane-limited polarographic type is the best available and will serve as the basis for the GEOSECS probe. Preliminary investigations indicate that the precision is better than one percent, with a lower detection limit of 0.05 ml/l of oxygen. To obtain this accuracy, calibration facilities are maintained on board ship. Figure 6 illustrates the results taken with the O_2 probe to a depth of 5,000 m and compared with laboratory determinations using the Carpenter-modified Winkler titrator.

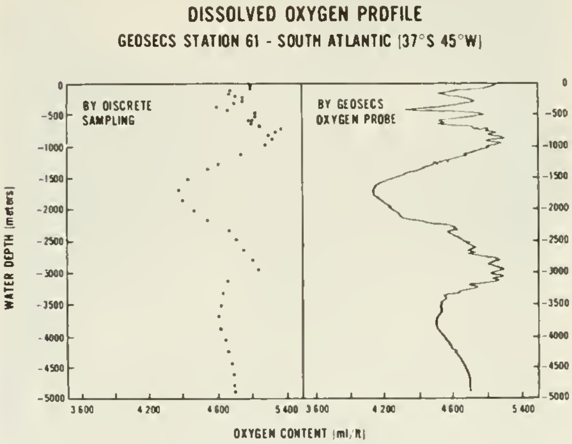


Figure 6

Nephelometry. To detect suspended particulate matter, a nephelometer is included in the underwater sensor package. This instrument uses a He-Ne gas laser beam light source. A resistive photocell placed just outside the beam detects forward-scattered radiation, and the response is a measure of the particulate matter in the water column. A similar photocell placed in the back-radiating beam of the laser monitors the emission.

pH and Carbonate Saturation. An instrument to measure in situ pH and carbonate saturation is being used in the Pacific legs of GEOSECS. The apparatus consists of two high pressure pH electrodes and a reference electrode attached to a pressure housing which contains the necessary electronics. An in situ pump periodically flushes a carbonate cell with surrounding seawater while the pH of the slurry is monitored continuously. The pH shift due to seawater-carbonate reaction is used to calculate the degree of saturation of the seawater with respect to the carbonate material.

Data Handling, Processing & Display

Data from the underwater sensor package are transmitted by frequency shift keying along the coaxial lowering cable. On board ship the raw data are recorded on analogue magnetic tape and directed to a Nova 1200 mini-computer for preprocessing. Selected portions of the data, normally about one in every sixteen data points, are transmitted to an IBM 1800 computer which maintains processed data files and controls four storage scopes which can be used to plot the data or any function thereof.

Profiles of salinity, temperature, oxygen and light scattering versus depth are displayed on two scopes, while density versus depth and potential temperature-salinity correlations are shown on a third scope. The fourth scope is used for temporary displays of detailed blowups of significant parts of the water column and for review of those laboratory systems that are interfaced with the computer.

As they are accumulated, discrete sample data are fed to the 1800, either directly or by punched cards, and station master files are stored which are available for review by the scientists within 24 hours of the start of the station. In addition, master files from past stations may be recalled at any time for comparison with the current data.

Large-Volume Water Sampling

Large-volume water samples are required for many of the radioactive elements measured during the project. Analysis of C^{14} requires 200 liters; Sr^{90} and Cs^{137}, 100 liters; Ra^{226}, 100 liters; Ra^{228}, 800 liters; and particulate matter, 250-400 liters of sea water. In some cases the same sample may be used for two or more measurements. A surface pumping system is used to obtain large-volume samples down to 250 m depths. The requirement of 18 large-volume samples per station necessitates both multiple casts and the use of multiple sampling devices (270-liter Gerard-Ewing samplers) on a single wire.

Shoreside Analysis

C^{14} and H^3—The GEOSECS project will generate about 1,200 C^{14} samples and about 2,500 H^3 samples. Of the C^{14} samples, about 900 most likely will be collected below 200 meters, and the greatest possible precision and accuracy is desired for these. In the C^{14} scale, a precision of better than four parts per mill, experimental errors included, was stipulated by the GEOSECS Advisory Committee and is being met by the researchers.

Analytical facilities were built at the University of Miami and at the University of Washington. No other existing radiocarbon laboratories in the U.S. can presently process a significant number of samples meeting these criteria.

Trace Elements—The Trace Elements Panel of GEOSECS has identified four trace elements—iron, zinc, barium and strontium—for principal study during 1972-73. All have an ocean-wide variance significantly in excess of the sampling and measurement error, and all are involved in processes of particulate transport in the oceans but probably with different fractions of the suspended matter. The possibility exists that iron is injected into midwater regions of the Pacific Ocean from the rift valleys of midocean ridges. Other elements will be determined at selected stations. Particulate matter samples and data being obtained as part of the GEOSECS program include: Concentration data throughout the water column; C, N and P in samples through the thermocline; distribution of elements such as Fe, Ba, Zn, Sr, Si and Al in suspended matter throughout the water column (by chemical electron scanning and x-ray probe techniques); and concentration, size fractionation, mineralogical and chemical composition data on detailed near-bottom profiles in the nepheloid layer.

Major Elements—Difference chromatography is used to study the proportional variations of the major ions in sea water. The sensitivity of the method is sufficient that

systematic variations in the Ca^{++} fraction of sea salt show up clearly and quantitatively. Ca^{++} profiles can be drawn and dissolution rates for calcium carbonate calculated.

Stable Isotopes—Variations in the C^{13}/C^{12} ratio of bicarbonate carbon are measured on a large suite of deep water samples. Shifts toward C^{13}-depleted carbon are used to evaluate the oxidation of detrital organic matter in deep water. Variations in the O^{18}/O^{16} ratio of dissolved oxygen are also being determined because they reflect the same oxidation process. Atmospheric water vapor variations in D/H and O^{18}/O^{16} ratios are of great interest for studies of the air-sea exchange of moisture and for estimating the latitudinal transport of atmospheric water.

Preparatory Cruises

Since the inception of the program, six intercalibration and testing expeditions were mounted, in which detailed vertical profiles were obtained: GEOSECS-I in the North Pacific, September 1969; GEOSECS-II in the North Atlantic, August 1970; leg 15 of S.I.O. Antipode Expedition in the South Pacific, August 1971; and the Gogo I and II reoccupations of GEOSECS-I in November 1971 and April 1972. GEOSECS-II was reoccupied by Knorr in July 1972. Of necessity, most of the work on these stations has involved intercalibration studies by U.S. and foreign investigators and extensive testing of equipment and techniques. Nevertheless, the results to date are important in their own right because of the detailed vertical sampling and the association of many types of measurements on the same water masses. The GEOSECS-I results were reported in the *Journal of Geophysical Research*, 75: 7696 (1970). In *Earth and Planetary Science Letters*, 15 (1972), some of the initial results are reported from Leg 15 of the S.I.O. Antipode Expedition. These include: The current status of the measurement of barium, an element of great importance because of its relationship to radium and silicon; recent developments in the extraction of Si^{32} and Ra^{228} on synthetic fibres; and the work done at the North Atlantic Station, GEOSECS II.

The Atlantic Cruise

The GEOSECS cruise track for the entire Atlantic Ocean was completed in March 1973 (Figure 7). The scientific and technological

Figure 7

goals of the program have been reached and in many respects exceeded. The concept and operation of a system for continuously measuring salinity, temperature, oxygen and nephelometry profiles have been proved. The precision obtained for these and other chemical determinations was better than those which had been taken as goals—in general, goals which until then were beyond the state of the art. The computing system used in the Atlantic legs enabled preliminary cruise reports to be produced in a few weeks.

Four large-volume stations in the North Atlantic (numbers 3, 11, 17, 19) have been designated key stations. Analyses of these stations were done on a priority basis by the cooperating laboratories so that results would be available for discussion at the Summer Institute held May 7-11, 1973, at Woods Hole.

Although it is too early to have sufficient scientific results at hand for evaluation, it is clear that GEOSECS data on the complex interfingering of water masses will produce a far more detailed picture than has yet been achieved and that our understanding of water movement will undergo a major advance.

ENVIRONMENTAL FORECASTING

The purpose of the IDOE Environmental Forecasting Program is to provide the scientific base necessary for an improved capability in predicting changes in the environment.

Long-range and accurate environmental forecasting depends on an understanding of the state of the oceans as well as of conditions in the atmosphere. In order to enhance forecasting capabilities, data on processes at work in the air and sea must be incorporated into predictive models. Since knowledge about these processes and mechanisms is incomplete, it is necessary to put major emphasis on studies of the ocean surface and its interaction with the lower atmosphere, and to determine the dynamic processes in the deep ocean that influence this interaction. Three projects focus on these problems: "Mid-Ocean Dynamics Experiment" (MODE); "North Pacific Experiment" (NORPAX); and "Climate: Long-Range Investigation, Mapping, and Prediction" (CLIMAP) program.

PROGRAM:

THE MID-OCEAN DYNAMICS PROGRAM (MODE)

The ultimate purpose of the Mid-Ocean Dynamics Experiment (MODE) is to establish the dynamics and statistics of meso-scale eddies, their energy sources and their role in general ocean circulation. It is estimated that these medium scale eddies, if indeed they are ubiquitous, contain at least as much kinetic energy as the mean ocean circulation and possibly ten times more. Where the energy comes from, how much is present and what it does are questions which must be answered in order to refine the numerical models that are the basis of environmental prediction. It is known that similar eddies exist in the atmosphere, that their kinetic energy content is comparable to that of the mean flow and that this is sufficient to prevent adequate numerical simulation unless it is properly taken into account. Such knowledge may be even more important to the proper modeling of the temporal and spatial behavior of ocean circulation.

The MODE consists of a continuing theoretical effort and a series of field experiments, two of which (MODE-0 and MODE-1) have been completed. The site chosen for the MODE-0 and the MODE-1 is an area of 600-km diameter and approximately 5-km depth near the Tropic of Cancer and southeast of the Bermuda Islands (Figure 8). The region was chosen for its lack of a strong mean current, convenience to the U.S. east coast and good Sound Fixing and Ranging (SOFAR) coverage. The MODE-0 field experiment, designed to provide additional information on medium-scale eddies prior to a more comprehensive field experiment, began in November 1971 and continued until the start of MODE-1 in March 1973.

MODE

Mode-0—The MODE-0 field program consisted of: Current measurements made with four series of current meter arrays, each of which contained two moorings at the same site; preliminary density and bathymetric surveys; and test deployments of SOFAR floats and bottom pressure gauges. Results from MODE-0 include: (1) the identification of 100 km as the scale (quarter-wavelength) of the medium scale eddies; (2) the determination that subsurface flotation for current meter moorings is the most practical method of enhancing signal-to-noise ratios; and (3) the discovery of numerous uncharted bottom features.

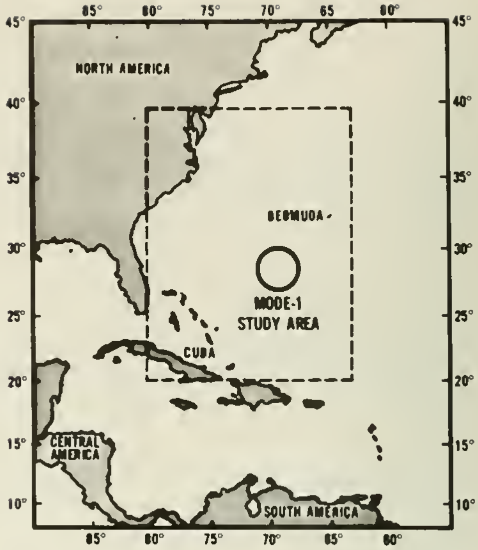


Figure 8 The area where the MODE-1 Field Experiment took place is shown on a physiographic diagram of the North Atlantic Ocean. The region within 200 km of the center of the array contained 20 instrumental moorings and 20 drifting buoys.

MODE-1—The MODE-1 field experiment took place from March-July 1973. It will also include limited extended measurements for a period of one year. Five ships from the U.S.—R/V *Chain* of Woods Hole Oceanographic Institution, O.S.S. *Researcher* of NOAA's Atlantic Oceanographic and Meteorological Laboratory, R/V *Trident* of the University of Rhode Island, R/V *Eastward* of Duke University and the R/V *R. F. Hunt* of Marine Acoustical Services—were joined by the R.R.S. *Discovery II* from England's National Institute of Oceanography. The ships conducted an integrated program of standard measurements of ocean temperature, salinity, and pressure fields (Figure 9).

The Moored Array—A fixed array of moored instruments consisted of recording current meters (about 94 on 24 moorings) and temperature/pressure recording instruments of new design. The current meters were concentrated at four standard levels—500, 800, 1500 and 3000 m—plus two deep levels, one of which is 100 m above the sea floor of the abyssal plain, and another at 4000 m in the abyssal hill terrain. The array was designed to help realize the following experimental objectives:

(1) pattern recognition over a circle of 350 km diameter;

(2) accurate mapping in an inner circle of 200 km diameter;

(3) thermocline, deep water and bottom geostrophic balances;

(4) precise float-flow intercomparison in the inner circle;

(5) information on the effects of intermediate scale rough topography on the coupled vertical and horizontal structures of the large scale patterns;

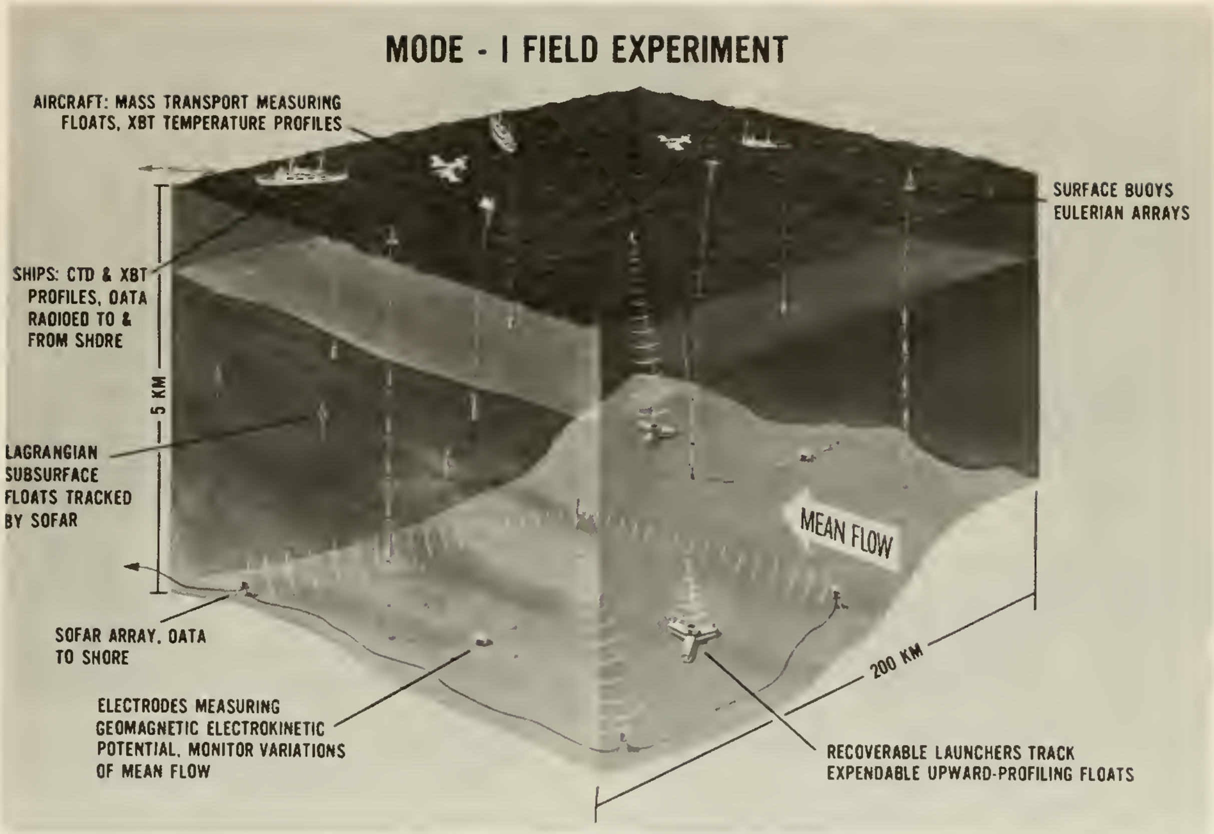


Figure 9

(6) extended pattern recognition at 3000 m depth.

Benthic Array and Floats—Superimposed on this fixed array of current meters was a second fixed array of benthic instruments for pressure and electric field measurements. Also included in the experiment were free-floating and profiling instruments including 20 large, neutrally buoyant floats situated near 1500 m depth in a sound channel. Moreover, determinations of transport over different depth ranges were made over the entire MODE region utilizing instruments dropped from aircraft.

Mini-Mode—The Mini-MODE experiment was situated in a small portion of the MODE-1 current meter, benthic, and float arrays. Five additional moorings were deployed with current meters at 500, 1500, 3000 and 4000 m in an area 100 km square and to the east of the central array. Within this region a total of 36 floats were launched to drift at depths, variously, of 500, 1500 and 3000 m. Mini-MODE was designed and executed largely by British oceanographers to examine features with spatial scales smaller than those which could be detected by the main arrays.

The Theoretical Program

Close scientific cooperation between theoreticians and experimentalists is essential to a successful investigation of medium-scale motions and to progress towards an understanding of their dynamic interrelationships. The development and application of numerical models is of great importance in several respects: the detailed design of field experiments; the development of synoptic mapping techniques; and the investigation of dynamical hypotheses. Numerical modeling is an essential tool in MODE in that it provides the link

between theoretical concepts and the design and interpretation of the field experiment.

During the planning phase of the MODE-1 project the theoretical panel played a key role. Important questions which were addressed included the effect of bottom topography on medium-scale eddies, optimum vertical and horizontal spacing of current meters to obtain "mappable" fields and float deployment and redeployment strategies. Future work by the theoretical panel includes determination of Lagrangian and Eulerian signatures for various possible causal mechanisms, construction of an ocean basin model and consideration of the effects of microscale. Naturally, many future aspects of the theoretical program will evolve in accord with insights gained from the field program.

Program Management

The various components of the MODE-1 are substantial experiments in their own right. Current U.S. participants in MODE represent eleven universities and two research institutes. Scientists from the National Institute of Oceanography in England have made a major contribution to the MODE-1 field project; other participating scientists are from the University of Cambridge, the University of Hamburg, the University of Goteborg and the Soviet Institute of Oceanology.

The MODE principal investigators form a scientific council, and specific, long-term problems are dealt with by special committees. For example, in addition to processing and interpretation by individual scientists of the data they gather, project-wide data analysis and interpretation is carried out by three committees—theoretical, intercomparison and synoptic. Day-to-day project management is provided by an executive officer who acts in concert with the two co-chairmen of the scientific council. Intermediate-scale problems are dealt with by an executive committee which is composed of seven scientists and includes the executive officer. Figure 10 illustrates the committee structure of MODE.

To provide for the demand of the MODE-1 field experiment for quick decisions and the careful weighing of differing needs, a special communications facility, the Hot Line Center, was maintained at the Bermuda Biological Station. The Hot Line Center provided daily radio contact with MODE ships and aircraft as well as a special telephone circuit to data analysis and scientific facilities in the U.S. In this manner early identification of features was assured, enabling field sampling programs to be modified accordingly.

PROGRAM:

THE NORTH PACIFIC EXPERIMENT

Between the dimensional and temporal limits of "weather," on the one hand, and of "climate," on the other hand, are substantial fluctuations of the ocean and atmosphere which involve time periods ranging from months to decades and which affect large portions of the earth's surface. It is this interval—intermediate between weather and climate—to which the North Pacific Experiment (NORPAX) addresses itself.

For five years the Office of Naval Research (ONR) supported a research program in the North Pacific to identify the oceanic processes relating to these anomalous "weather" conditions. Large areas of anomalously hot or cold sea surface temperatures (anomalies related to 30-year monthly mean values) were identified in the North Pacific. It was postulated that these sea surface temperature anomalies, via ocean-atmosphere coupling, affect the climate from the Eastern Pacific eastward across the entire North American continent (Figure 11a, 11b).

Indeed, a direct correlation appears to have been established between (a) such sea surface temperature anomalies and the correlate migration of an anomalously deep atmospheric trough from 155° E in September 1972 to 90° W in May 1973, and (b) the heavy winter and early spring rains in California and the southwest, the flood-producing spring rains and tornadoes in the central U.S. and the New England floods of June. Obviously, major atmospheric perturbations in an area as large as the North Pacific will have impacts not only in adjacent regions—Asia, the Arctic, North America and the South Pacific—but much more remotely as well. To the extent, for example, that Pacific-born weather off the New England coast affects sea surface tem-

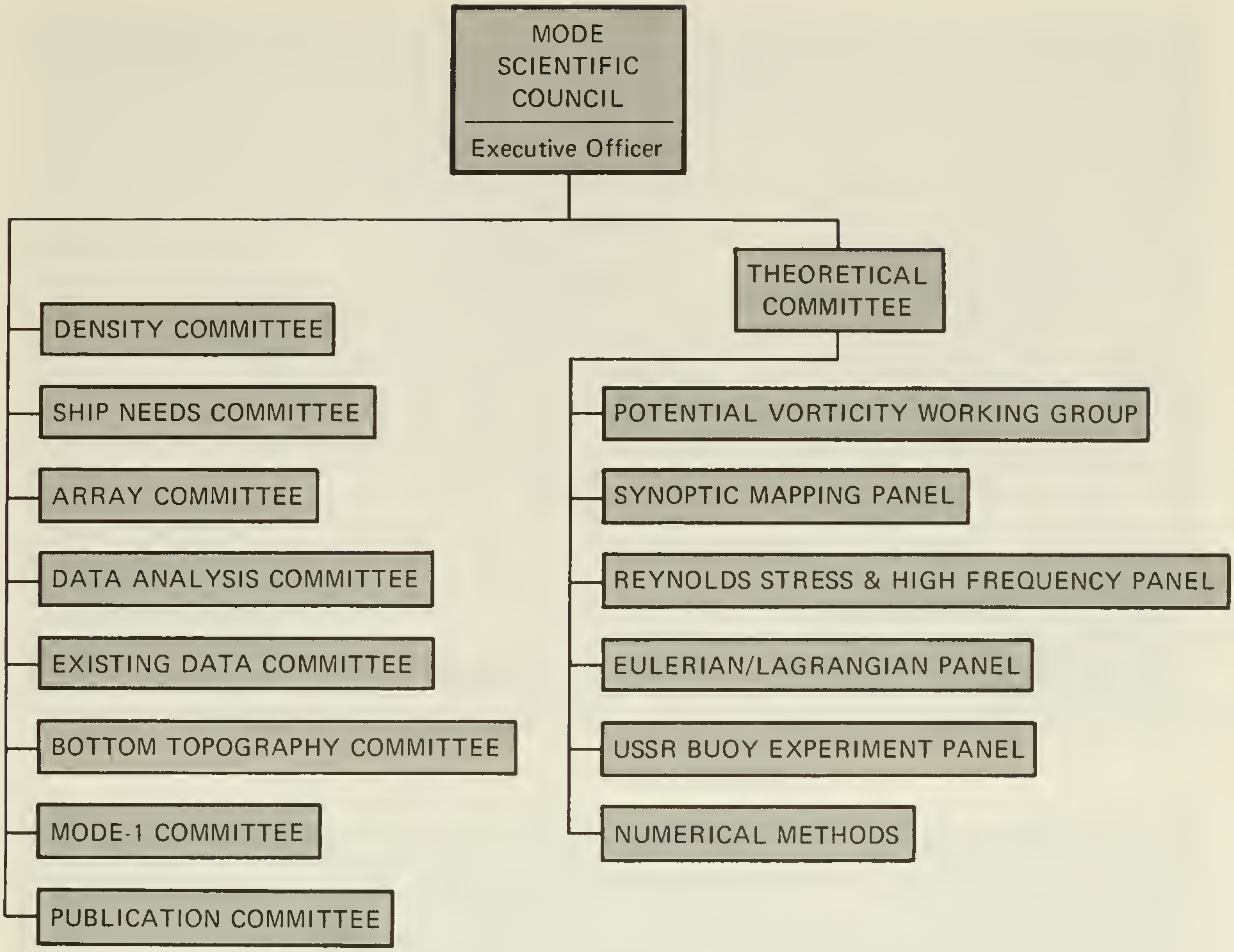


Figure 10

peratures and other phenomena in the western North Atlantic, weather in Western Europe is to some degree controlled by conditions in the North Pacific area.

It became obvious that the ongoing level of effort for this research program was insufficient to discover the causes of a number of environmental phenomena so far identified. Thus, the resources of International Decade of Ocean Exploration (IDOE) and ONR were combined to produce a larger and more comprehensive effort than either could support alone.

Objectives

The major objective of NORPAX is to describe and develop a basis for explaining the mechanisms responsible for the large-scale oceanic and atmospheric fluctuations that occur in the mid-latitudes of the North Pacific Ocean. The fluctuations may be described in terms of complex interactions between and within major oceanic and atmospheric systems. All of the contiguous systems and regimes in the North Pacific Basin interact with each other to some degree. This fact makes it clear that NORPAX must consider the entire sequence of systems.

To achieve this objective, research efforts are concentrated in two main areas of study: investigations of the total North Pacific system; and investigations of regional interactions (e.g., how fluctuations in the position and strength of the Aleutian Low affect the North Pacific Current).

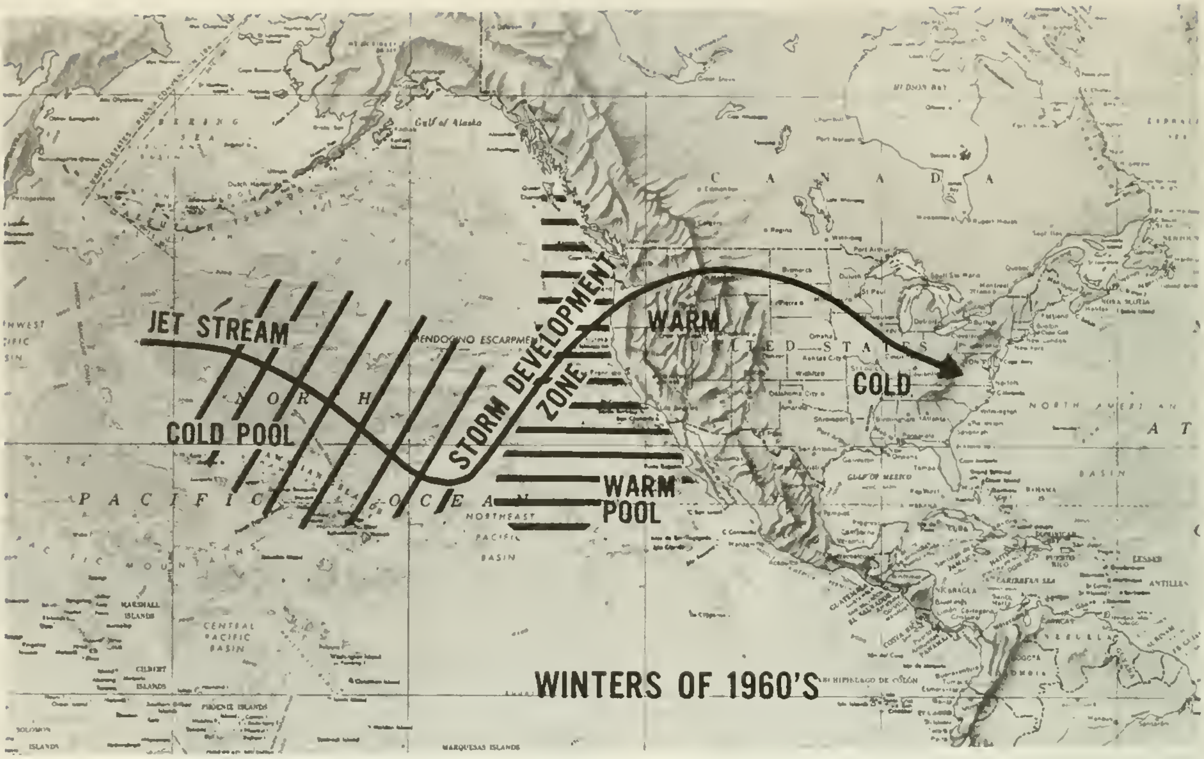


Figure 11a

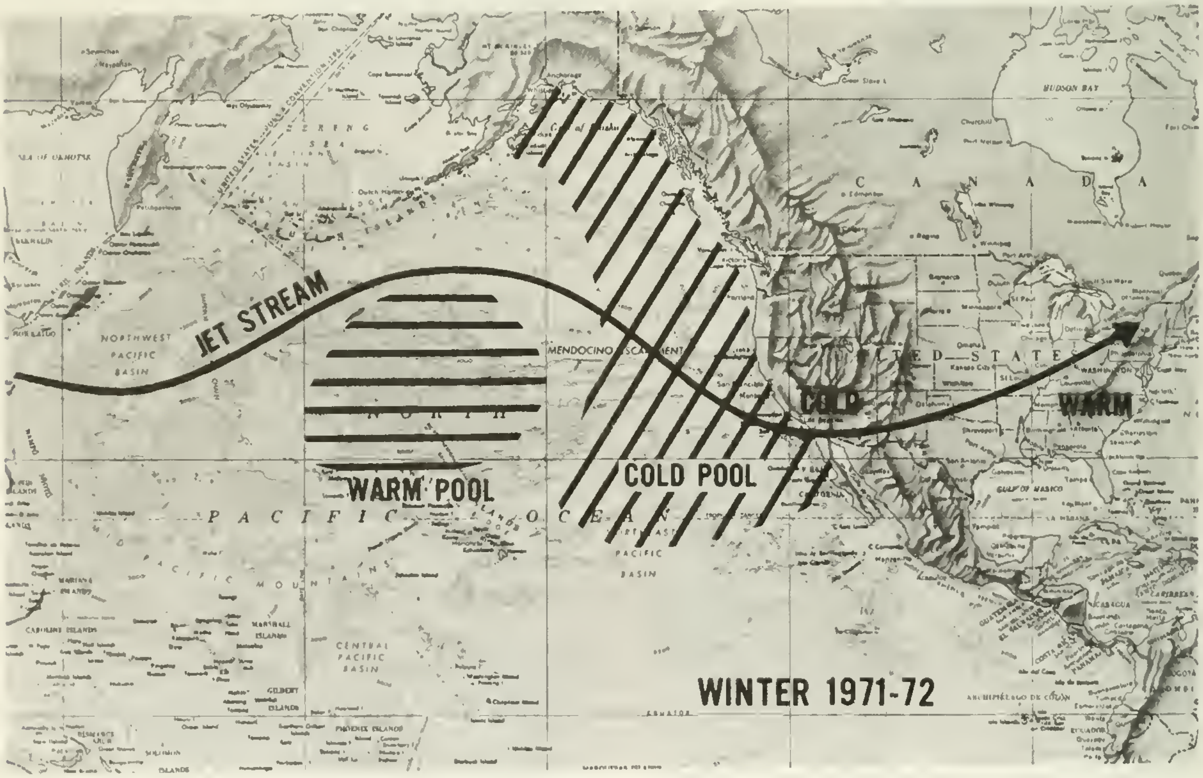


Figure 11b

Methodology and Operations

These studies proceed by formulating a set of working hypotheses to be tested. For example, consider two general hypotheses of the type that may account for large-scale ocean-atmosphere fluctuations over the North Pacific Ocean.

Hypothesis I: That major fluctuations in the central Pacific are induced by air/sea interactions occurring in the equatorial regions.

Hypothesis II (the reverse of hypothesis I): Cycles observed in equatorial regions are explained in terms of central North Pacific phenomena; these latter events, the ones which affect North American weather, are induced primarily by "local" mechanisms.

Each hypothesis has incorporated a number of lesser conjectures. However, the first job in verifying either hypothesis is to determine experimentally the nature of the interaction between equatorial and mid-latitude systems. This requires a determination of the dominant processes responsible for the energy and momentum exchange in the North Pacific Basin; the monitoring of important regions and determination of the time histories of the major ocean and atmosphere systems in the North Pacific Basin; and the measurement (if possible) or derivation of the energy and momentum exchanges between the individual systems and/or regions. The experiment involves four major operational phases. Phases I and II will take approximately one and one-half years and involve development of theory (numerical models), test and development of skeleton data-gathering and scientific support systems. Based on the results and knowledge gained during Phases I and II, the data gathering network will be optimized during Phase III. Phase IV will involve operation of the data gathering system and analysis of incoming data. It should be emphasized that scientific research on all aspects of the problem is carried out continuously during all four phases.

Program Management

Much of the scientific direction and planning of the project is carried by the Co-Principal Investigators' Panel, which consists of the scientists actively doing research within NORPAX. The Panel's main responsibility is to help formulate the general scientific aspects of the overall program, with particular emphasis on each Principal Investigator's individual area of interest and expertise. Equally important areas for their attention will be the composition and balance of the main program and determination of NORPAX data needs. A Scientific Advisory Panel, composed of scientists not actively doing research in this project, has been established. It critically reviews the plans, direction of effort and past performance of the project and advises the funding agencies as well as the project participants.

For the North Pacific Experiment to be truly successful, a commitment of resources beyond those of ONR/NSF and the United States will be necessary. Scientists of other nationalities are invited to bring the resources of their countries to bear on aspects of the major scientific objective. Within the U.S. one of the NORPAX project goals is to establish appropriate working relationships with other governmental groups.

PROGRAM:

CLIMAP

Objectives

Research associated with the third major project in the Environmental Forecasting Program focuses on the description and understanding of climatic changes over the last 700,000 years. An accurate definition of these changes over such a time scale is mandatory if scientists are to understand the transition between what are currently considered the two stable states of global climate, the ice age and the temperate age. By comparing an accurate description of this transition to that predicted by models of global climate, a better understanding of the mechanisms of climatic change will be achieved. The CLIMAP project should shed light on such basic questions as whether changes in climate are due to fluctuations in solar radiation, or whether they are caused by changes in the earth's hydrosphere. A thorough understanding of climatic changes is necessary if we are to comprehend our present place in the natural cycle. Moreover, such knowledge is important in order to assess and to anticipate the effects of man's activities on the global environment.

Work Plan

The CLIMAP project seeks to answer these important questions through the study of deep-sea sediments. When compared to the scanty record kept by man on changes in the oceans and atmosphere, the layers of sediment on the seafloor provide a rich source of data. Indeed, an excellent chronological record has been captured in the ocean-bottom sediment cores which are preserved in marine geological archives (Figure 12). Recent advances in dating techniques, automated analyses of individual sediment cores and computer correlation of the many features in the sediment strata make it possible to generate global-scale summaries of past sea surface conditions.

Paleo-oceanographic maps are being constructed for four selected periods: 6,000 years ago (the post-glacial thermal maximum), 17,000 years ago (the last glacial stage), 120,000 years (the last interglacial stage), and 700,000 years ago (the mid-Pleistocene base). Comparable maps for the present form the basis for interpretation. Presently available core archives are adequate to provide sample material for the study. The general plan of research work includes:

a. A survey of existing core collections to determine those most suitable for use as the base grid for the paleo-oceanographic study. This consisted primarily of routine paleontological examinations and was completed during the first year of the project;

b. The acquisition and initial interpretation of paleontological, sedimentological, and geochemical data on suitable grids for all "time" levels;

c. Extension and consolidation of present work on quantitative relationships between the oceanic environment and sediment properties is followed by multivariate analysis to provide interpretative paleo-oceanographic maps for each level;

d. The close coordination of the results of this study with those of the ongoing examination of Greenland and Antarctic ice cores. These comparisons promise to yield critical information regarding high latitude glacial and interglacial climates and their effect on the temperature and salinity of bottom and surface ocean waters.

The methodology described above has been applied to produce a map of the sea surface temperatures in the North Atlantic 17,000 years ago. It is interesting to compare this pattern, illustrated in Figure .., with that presently observed in the North Atlantic (Figure 13). Such maps can now be used as an input to, or a check of, the product of numerical models.

Program Management

This is an integrated project in which some data are produced by many individual specialists and experts, but in which data interpretation is a joint effort of all participants. Coordination is achieved by a management structure consisting of an executive committee and a number of task groups. The Executive Committee consists of five members who: 1) assume overall responsibility for the project; 2) coordinate and assure the free flow of information among institutions; 3) assure coordination among task groups; and 4) set and implement policy.

Figure 12

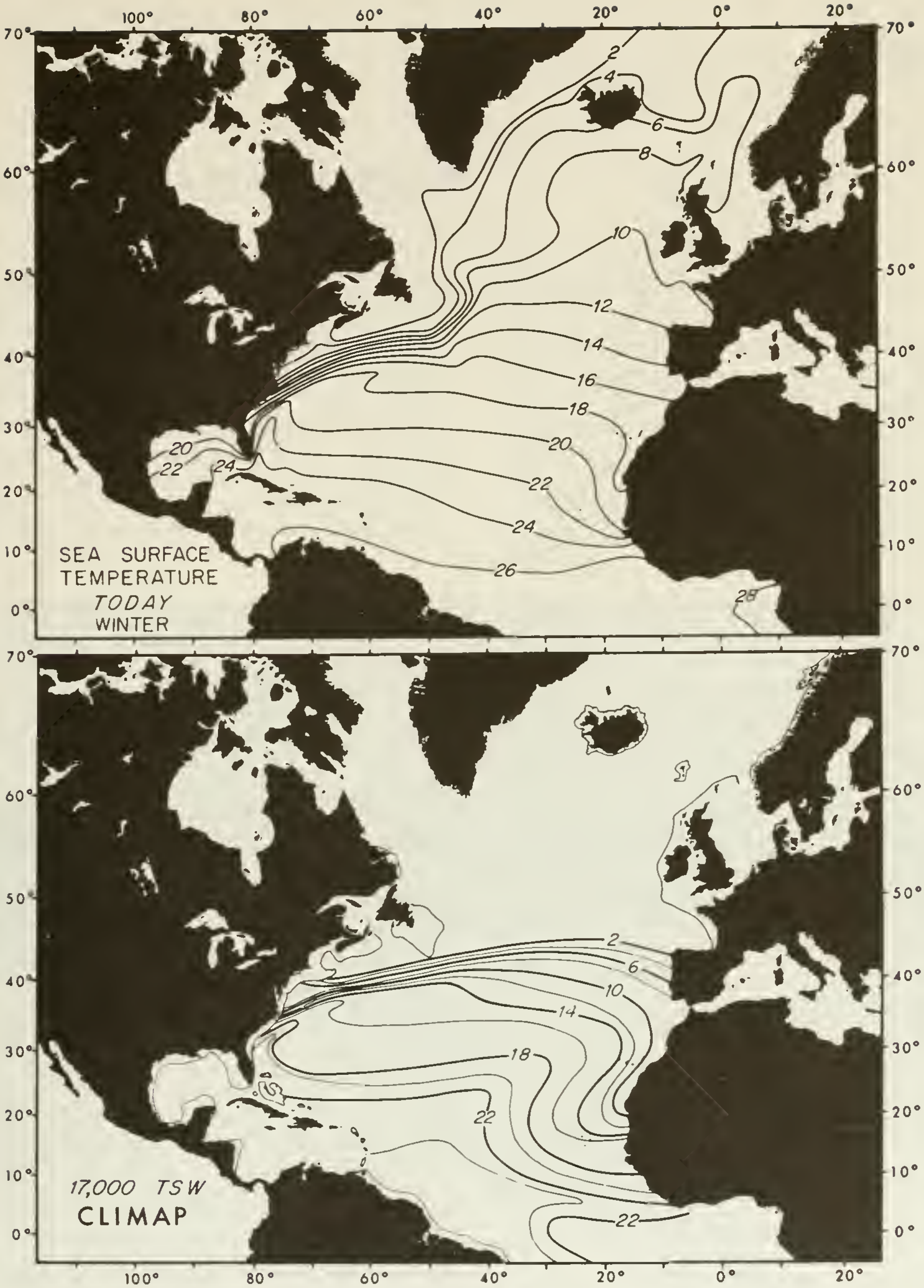


Figure 13 Maps of the average sea surface temperatures (in degrees Celsius) during the recent winters and 17,000 years ago. The recent map (top) represents a synthesis of oceanographic data, while the 17,000 year CLIMAP (bottom) is constructed from estimates of past temperatures based on the fossil foraminifera in approximately 90 deep-sea cores from the Atlantic.

SEABED ASSESSMENT

The Seabed Assessment Program is designed to increase understanding of the geologic processes active along the continental margins, the mid-oceanic ridges and the deep ocean basins (Figure 14) which generate the raw materials (e.g., petroleum and heavy metals) of our modern industrial civilization. The obvious deposits have already been found. However, new sources must be located, and the results of these seabed investigations already materially aid resource geologists in that search.

PROGRAM:

CONTINENTAL MARGIN STUDIES

The continental margins are important for both economic and scientific reasons. Rich deposits of sulfur, heavy minerals, sand, and gravel are dredged from the bottom. Except for a few areas where oil fields have been developed, however, the continental margins of the world remain largely unknown (Figure 15).

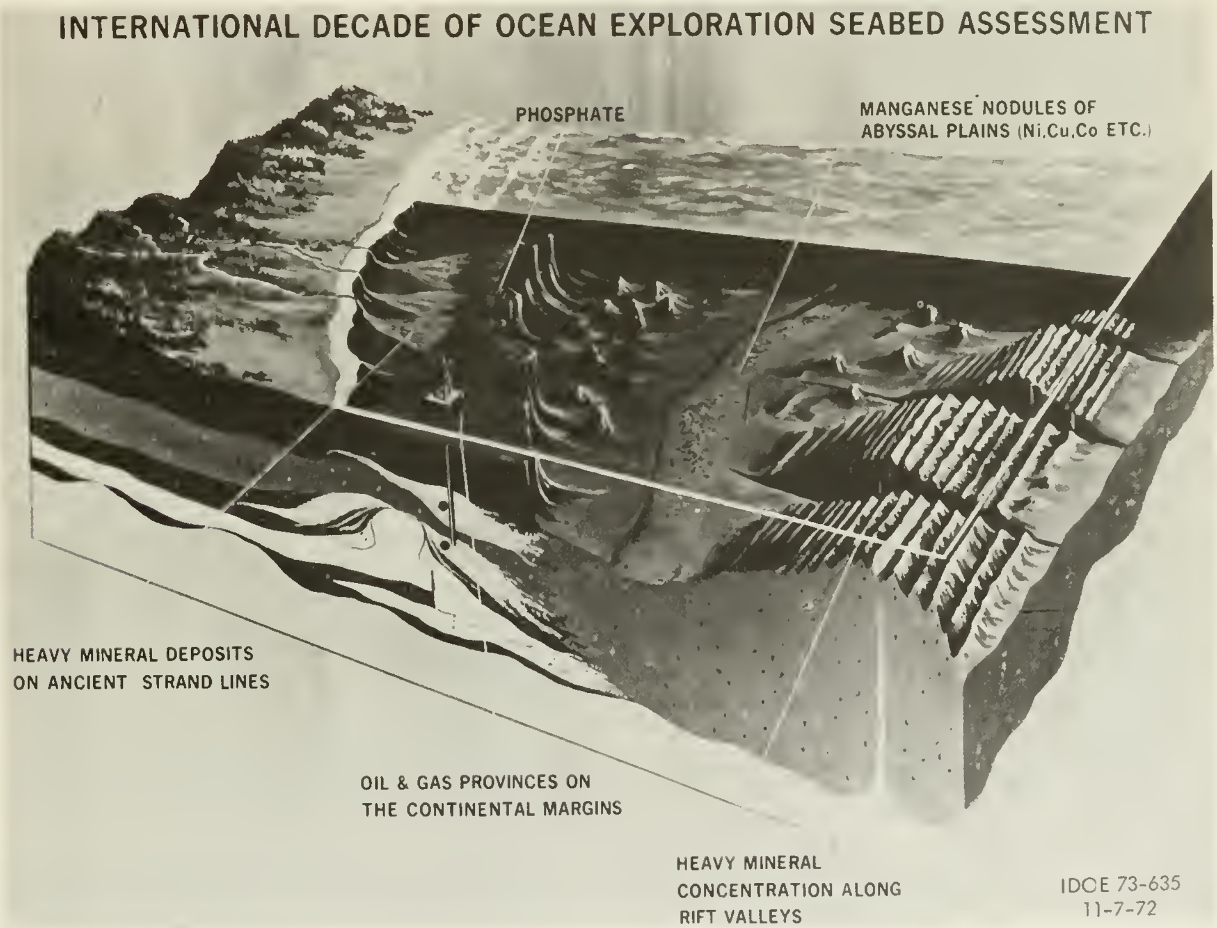


Figure 14

CONTINENTAL MARGINS OF THE WORLD

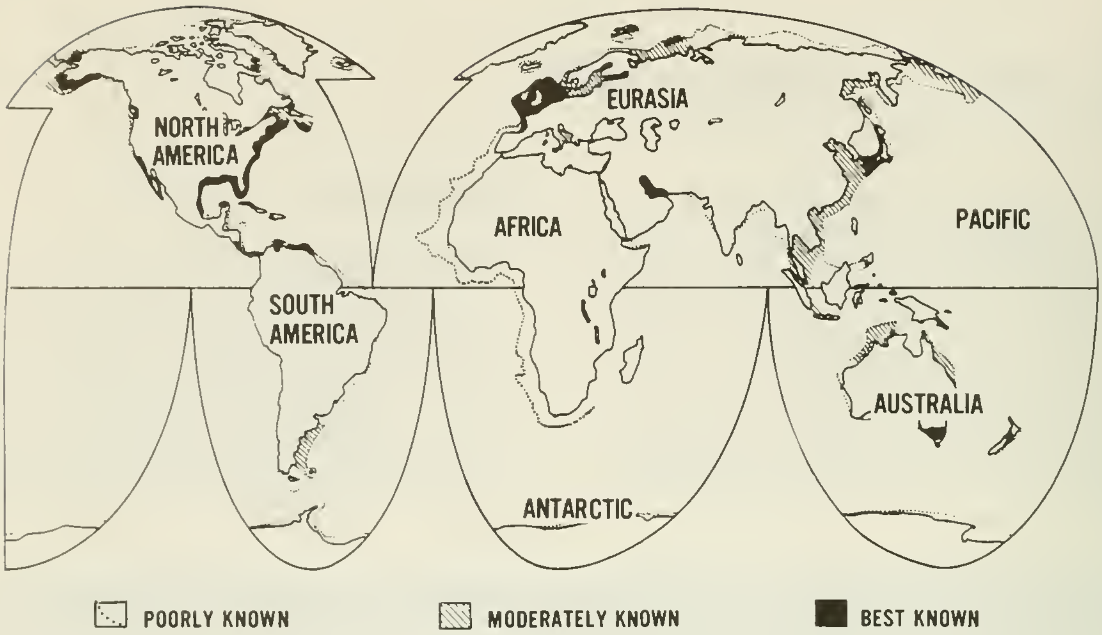


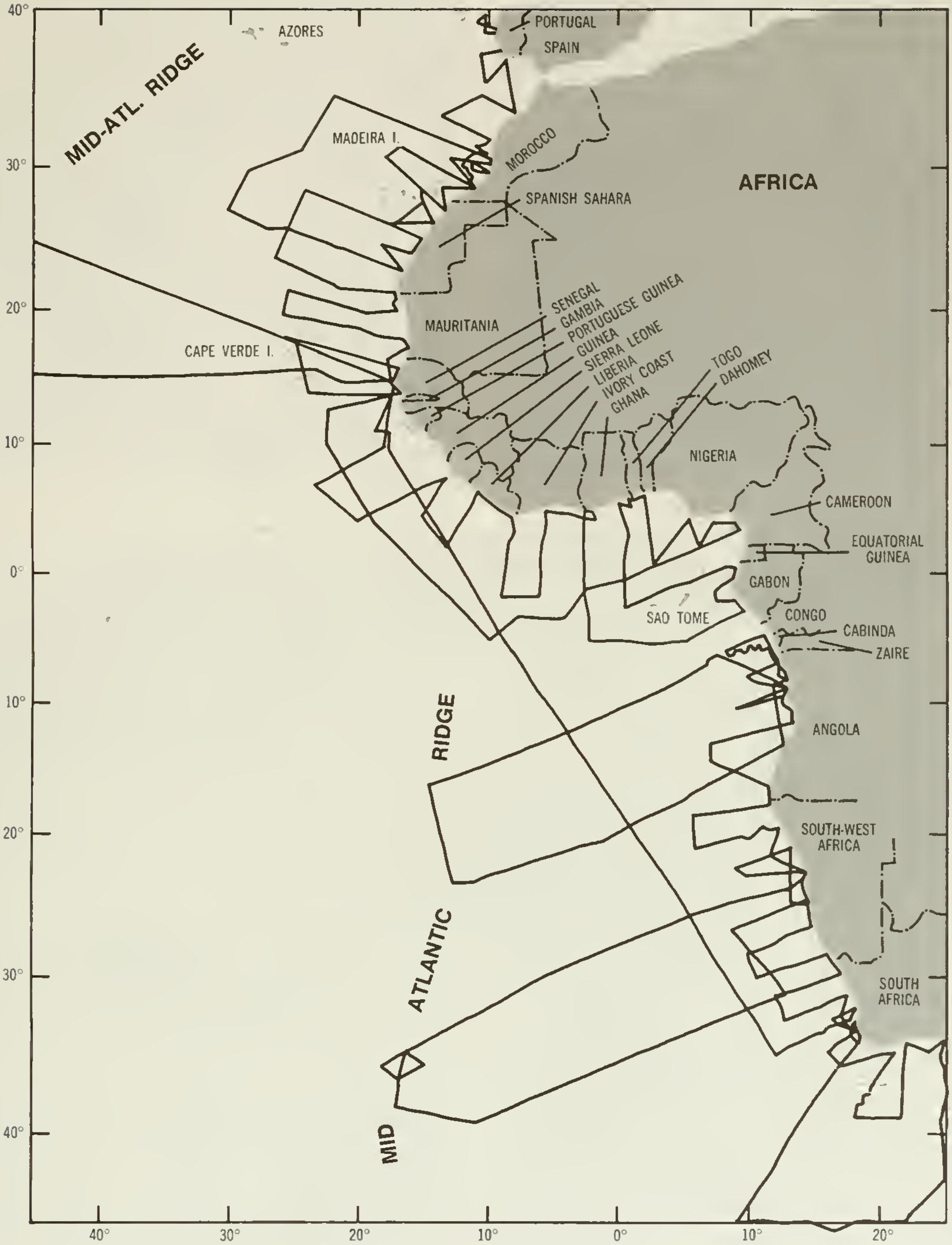
Figure 15

Program of Work

Major studies of the continental margins along the South Atlantic are now under way. One study off west Africa extends from South Africa to Portugal; another along the east coast of South America extends from Argentina to Brazil. The African studies were initiated in January 1972 when scientists from the Woods Hole Oceanographic Institution began a systematic study extending from Port Elizabeth, South Africa to the Congo River. Although survey tracks concentrated on the continental margin, a few tracks were extended out to the Mid-Atlantic Ridge. A total of 50,000 km of seismic reflection, gravity and magnetic data were recorded. Precision bathymetric data were also obtained, and seismic refraction data, using sonobuoys, were routinely recorded. Location of lines at sea was controlled by satellite navigation. In 1973 the second and final cruise extended the study from the Congo River to Lisbon (Figure 16).

African Atlantic Assessment

Preliminary findings from the 1972 work indicated two potential sources of oil accumulation, one in a thick sedimentary section off the delta of the Orange River in southwest Africa, and another in a large diapiric salt basin off Angola. The areal extent and thickness of both deposits were outlined using geophysical methods, and their internal structure has been analyzed using seismic reflection and refraction data. K. O. Emery, the Principal Investigator from Woods Hole, concluded that: "Within the delta are probably numerous stratigraphic traps capable of retaining oil and gas if they are present and within the diapir field are many structural traps caused by the upward movement of the salt. The landward side of both features underlies the outer continental shelf or the upper continental slope, but the major parts lie much deeper. Nearly all of both features lie within 200 nautical miles . . . of the adjacent coasts. While depths



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AFRICA
SPANISH SAHARA
SENEGAL
GAMBIA
PORTUGUESE GUINEA
GUINEA
SIERRA LEONE
LIBERIA
IVORY COAST
GHANA
TOGO
DAHOMEY
MAURITANIA
CAPE VERDE I.
NIGERIA
CAMEROON
EQUATORIAL GUINEA
GABON
SAO TOME
CONGO
CABINDA
ZAIRE
ANGOLA
SOUTH-WEST AFRICA
SOUTH AFRICA
MID ATLANTIC RIDGE
40°
30°
20°
10°
0°
10°
20°
30°
40°
40°
30°
20°
10°
0°
10°
20°

Figure 16

of more than about 100 m are too great for present economic exploitation of oil and gas, they may justify testing by the drill within a decade. Successful exploitation of the deep-water features can greatly modify the economy of the adjacent countries and broaden the petroleum supply for the rest of the world."[1]

On one or more of the various legs, twenty-one scientists, technicians and students from Argentina, Brazil, the Republic of the Congo, the United Kingdom, France, Portugal, the Republic of South Africa and Spain participated. Preparatory to the cruise about 150 African and other interested scientists received a bathymetric atlas and preliminary reports on geomagnetics, gravity and sediments. The profiles and charts of geophysical data from the 1972 cruise were printed and distributed in January 1973.

South American Atlantic Assessment

A similar study, being carried out in the southwest Atlantic extends from the Scotia Ridge to the Caribbean. This cooperative program involves scientists from the Lamont-Doherty Geological Observatory, the Woods Hole Oceanographic Institution, Brazil, Argentina and France. A significant portion of the work is being done from a Brazilian research vessel, and scientists from both Brazil and Argentina have received additional training aboard ship and in residence at Lamont and Woods Hole. The study includes the entire western margin of the South Atlantic as a unit. The thickness and areal extent of the entire sedimentary section is being measured, its internal structure is being analyzed, and, where geological formations subcrop along the ocean bottom, samples are taken in order to work out a stratigraphic section. In areas of great sedimentary thickness, such as the Amazon cone, a two-ship refraction technique is used in order to record the depth and attitude of the acoustic basement. The prominent fracture zones are mapped in order to answer questions involving their relationship to margins off Africa. For example, the diapir-like structures of the São Paulo Plateau appear to be the counterpart of the diapir field off Angola. The Rio Grande Rise, off Brazil—the target of an investigation by French scientists—may have played the same role in controlling the salt deposition as the Walvis Ridge off Africa. Indeed, in the early stages of rifting they may have been parts of the same structural feature. Further definition of the several sedimentary basins off Argentina and detailed study of the Malvinas (Falkland) Plateau and Scotia Ridge—the active segment of the southwest Atlantic continental margin—will add to our understanding of how South America and Africa separated.

Paleogeographic Maps—Concentrating on the continental margins on both sides of the South Atlantic simultaneously has broad appeal. The exactness of the geometrical fit of the continents offers a textbook example of the way they may have been united (Figure 17) and suggests that the process of spreading must have been relatively straightforward here. The concepts which evolve from a study of these margins will form useful working hypotheses for other, perhaps more complicated, margins.

A significant product of this cooperative investigation will be a series of paleogeographic maps, one for each successive stage of the "opening" of the South Atlantic Ocean. Despite the acceptance of the general principle that present day geologic conditions are a key to the past, it is difficult to account for either the existence of 500-million-barrel oil fields or the enormously thick salt deposits in the geologic column. A reconstruction of geologic conditions during past geologic ages may provide an understanding of the causes of these phenomena.

New continental margin studies may be undertaken when international groups of scientists recommend major areas or problems which can best be investigated on a large-scale, cooperative basis.

PLATE TECTONICS AND METALLOGENESIS

Geological processes operating along mid-oceanic ridges and active trenches may be responsible for the generation of heavy metal ore deposits. Metalliferous sediments and hydrothermal rocks in the crust have been dredged up from the ocean bottom near the active spreading centers. Heat-flow measurements show anomalously high values in these

[1] K. O. Emery, "Eastern Atlantic Continental Margin. Some Results of the 1972 Cruise of the R. V. Atlantis II," *Science*, Vol. 178, Oct. 20, 1972, p. 300.


150 TO 200
MILLION YEARS AGO


80 TO 120
MILLION YEARS AGO


TODAY

Figure 17

zones suggesting that the metal-rich crust and overlying sediments emanate from the rift and move toward the active trenches (Figure 18). Preliminary isotope studies suggest that ore bodies in igneous rocks above subduction zones result from partial melting of the subducted crust—the melting of which in conjunction with upward transport through volcanism can be considered the second stage of a two-stage geochemical enrichment process. Since such ore bodies are known only on land, the study of metallogenesis on the margin edges will be a partial contribution to the understanding of a much larger problem.*

Nazca Plate

The Nazca Plate (Figure 19) has been recognized as suitable for a detailed investigation of the complete cycle from crustal formation along the East Pacific Rise to its consumption in the Peru-Chile Trench. The presence of major ore deposits in the Andes overlying the zones of subduction supports the thesis that they originated through this process. The Nazca Plate is small enough to be studied as a single geologic entity yet large enough to be representative of the great lithospheric plates which make up the surface of the earth. Since the spreading rate along the East Pacific Rise is among the most rapid yet measured, the volcanic processes producing metalliferous crust and sediments must be quite intense. Furthermore, because the Plate itself receives little sediment from the land, the dilution process must be minimal.

The Hawaii Institute of Geophysics, Oregon State University and the Pacific Oceanographic Laboratory of NOAA are conducting a study of the plate margins using complementary geophysical, geochemical and geological techniques. Scientists from Colombia, Ecuador, Peru, and Chile are all actively participating in the cruises and data analysis. Simultaneously, a large-scale geophysical study of the subduction zone under the Andes, as it extends from Colombia south through Chile, is being carried out. Although this study goes beyond the scope of IDOE, the data on the subduction zone has obvious implications for the Nazca Plate metallogenesis study and vice versa.

* Guidelines for metallogenesis proposals are available from the IDOE Office.

THE GENESIS OF COPPER DEPOSITS

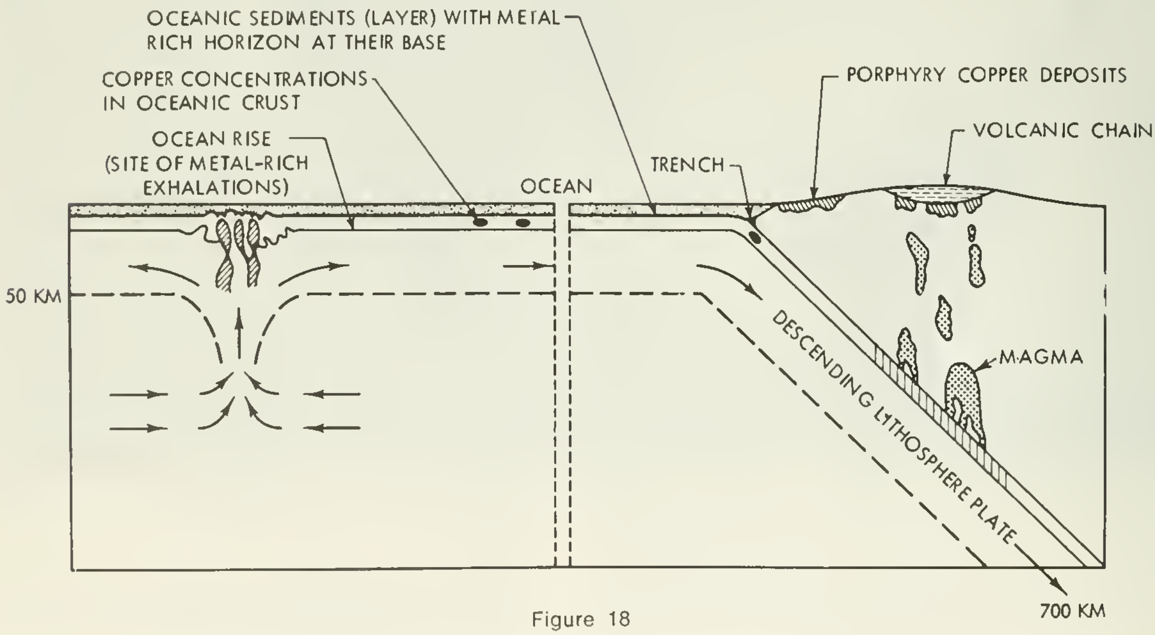

Figure 18

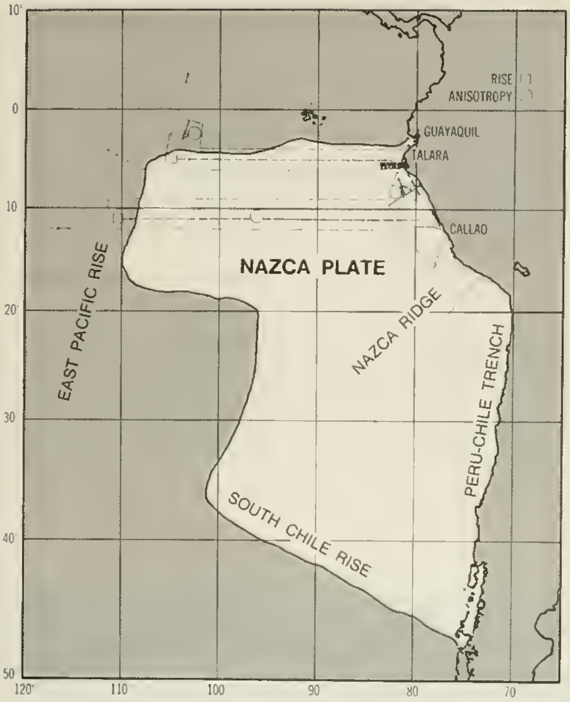

Figure 19 Nazca Plate

The East Pacific Rise extends northward into the Gulf of California where high heat flow values and swarms of microseisms have been recorded. Scientists from the Scripps Institution of Oceanography and the University of Mexico are making a detailed study of the associated rift valley because of its analogy to the Red Sea rift valley, where heavy metals have been detected in the hot brines.

Mid-Atlantic Ridge

Better understanding of the geological processes operating along mid-ocean ridges is the basis for a study of the Mid-Atlantic Ridge. Despite numerous individual studies of this feature, knowledge is really quite limited, and nothing is known at scales smaller than approximately 20-50 km.

Prior to undertaking a major study of the Mid-Atlantic Ridge, IDOE supported a National Academy of Sciences workshop to examine major questions concerning the processes operating along the crest. Scientists from Canada, France, Iceland, the Netherlands, the United Kingdom and several U.S. institutions met at Princeton in January 1972. The workshop results summarize our present knowledge and outline a comprehensive program for a concerted attack on the major problems.[2]

The workshop identified five programs as high-priority field projects, as follows:

- Long-range (1,600-to-2,000 km) seismic refraction measurements to provide information on the geometry and physical properties of the deeper lithosphere, the asthenosphere and the transition zone—with emphasis on variations with distance from the accreting plate boundary (i.e., the Mid-Atlantic Ridge).
- Detailed geological and geophysical studies, to include interdisciplinary surveys on a rifted ridge crest, a nonrifted ridge crest, a large equatorial transform fault and a fractured plate.
- Comprehensive geological and geophysical surveys, particularly short-line seismic refraction and dredging to obtain a complete set of rock samples from 72°N to 36°N. Also suggested are reconnaissance surveys in the South Atlantic, just south of the highly fractured equatorial region.
- Bottom stations and instruments to record seismic signals from natural or man-made sources, water currents, temperature, magnetic and electric variations, chemical concentrations in seawater, pressure and other variables. The report notes that many such instruments, while within the state of the art, nevertheless need to be developed.
- Island stations and studies, including seismograph stations on islands on or near the ridge crest to define details of seismic activity on ridge crests and in fracture zones, deep drilling (3-to-4 km) into the axial zone, continued geodetic measurements on Iceland and the deployment of hydrophones in the Sofar Channel from a variety of island stations as a means of locating microseisms.

Scientific exploration of the ocean floor will enter a new phase with the Mid-Atlantic

[2] *Understanding the Mid-Atlantic Ridge, A Comprehensive Program*, National Academy of Sciences, Washington, D. C., 1972.

Ridge Study. Present knowledge, based on studies from surface ships, is analogous to geophysical surveys on land made from altitudes of 5,000 m. Submersible craft will enable scientists to make first-hand observations of the active zones, collect samples and precisely emplace instruments. French and U.S. submersibles and the United Kingdom's deep-towed vehicle *Gloria* will be used in the area southwest of the Azores (Figure 20).

Preliminary surveys are now being carried out to select the tectonically most active points in the rift valley of the ridge. The techniques include detailed depth soundings, seismic reflection profiles, ocean-bottom seismicity data, heat flow data and sediment samples. In addition to the United Kingdom, France and the United States, Canada, Iceland and Portugal plan to participate.

Other studies of processes operating along the Mid-Atlantic Ridge are now being planned. They will emphasize the genesis of metals during formation of the crust and their subsequent conversion into ore deposits of potential economic interest.

MANGANESE NODULES

The third major investigation concerns the origin and distribution of concretions commonly referred to as manganese nodules.

Figure 20 © Courtesy of National Geographic Society

Polymetallic nodules is a more descriptive term for these formations since, in addition to high percentages of iron and manganese, the nodules sometimes contain copper, nickel and cobalt in economically attractive amounts. Until recently the nodules, which occur extensively on the abyssal plains of the ocean, were regarded merely as a geological curiosity.

Manganese Nodule Workshop

In order to assess the present state of knowledge and to plan future studies, the Lamont-Doherty Geological Observatory under IDOE auspices held a workshop/conference in the winter of 1972. The workshop covered scientific, technological, economic and environmental aspects of manganese nodule deposits. Since most deposits lie beyond the limits of any present claims to national sovereignty, some attention was given to international legal considerations. Thirty papers were presented, and the workshop results have recently been published.[3]

Although the workshop helped to clarify the understanding of the major aspects of the subject, it also focused attention on a number of problems and gaps in present knowledge. There was general agreement that the substantial amounts of information in core labs and data banks should be inventoried and published. Reports on the North Pacific deposits and the chemical and physical properties of ocean sediments have already been published (Figure 21a, 21b, 21c [4]). A coordinating office was set up at Lamont to administer a multifaceted definition study being done by ten investigators from Columbia University and ten more from as many other institutions. The results of the definition study and recommendations for future research have been published.[5]

Recommendations

Recommendations—The report and recommendations, to be used as guidelines for future research, should be valuable to all groups interested in studying the mineral potential of the ocean. IDOE is especially interested in those aspects which relate to the origin and distribution of the nodules, for example:

- Sources of and reasons for compositional variations, modes and rates of growth of nodules and crusts and the significance of their stratigraphic records;
- Environmental factors, including parameters by which minor element composition may be predicted, relationships between deposits and associated life forms and the environmental impacts of large-scale mining and processing;
- Concentrated studies of specific deposit regimes, including at least one Pacific site that is important both scientifically and economically;
- Investigatory and assessment methods by in-situ observations, sampling, analysis and data management;
- Information and data necessary to the planning and management of this resource at the industrial, national and international levels.

In general the report urges that future research be characterized by a sharper focus than has been the case in the past, with emphasis on the testing of specifically stated hypotheses. It also recommends that the fullest possible use be made of existing nodule specimens and that existing centralized nodule information sources be continually maintained and updated.

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[3] David R. Horn, ed., Papers from a *Conference on Ferromonganese Deposits on the Oceon Floor*, Arden House, Harriman, N. Y. and Lamont-Doherty Geological Observatory, Columbia University, January 20-22, 1972, New York, 1972.

[4] D. R. Horn, B. M. Horn, and M. N. Delach, *Ferromanganese Deposits of the North Pacific, Technicol Report Number 1*, Lamont-Doherty Geological Observatory, Columbia University, New York, 1972.

[5] Inter-University Program of Research on Ferromanganese Deposits of the Ocean Floor, Phase I Report, April 1973. Lamont-Doherty Geological Observatory, Columbia University, New York, 1973.

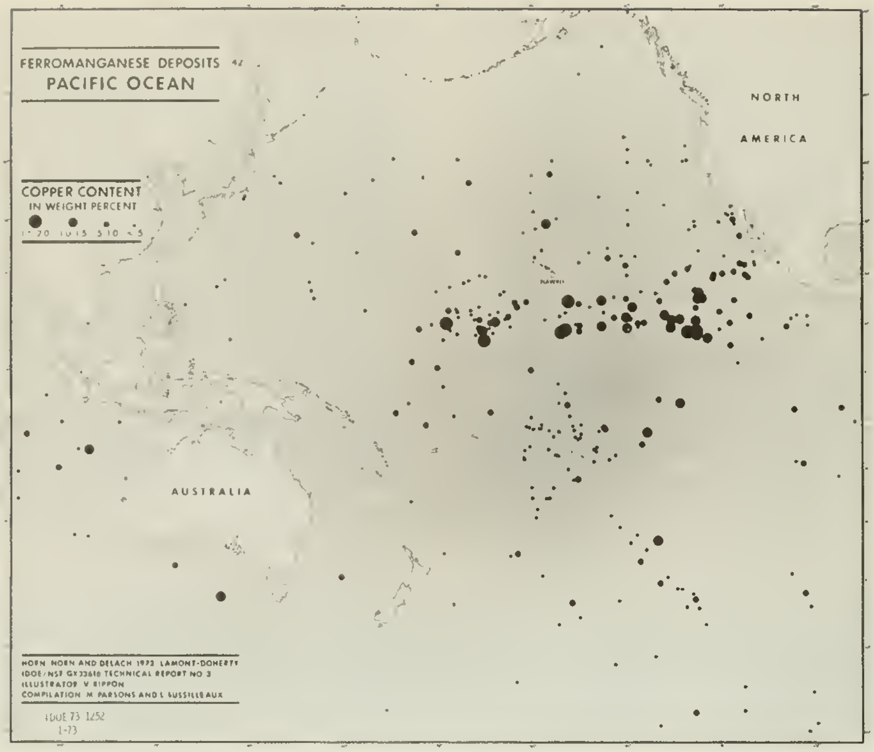


Figure 21a

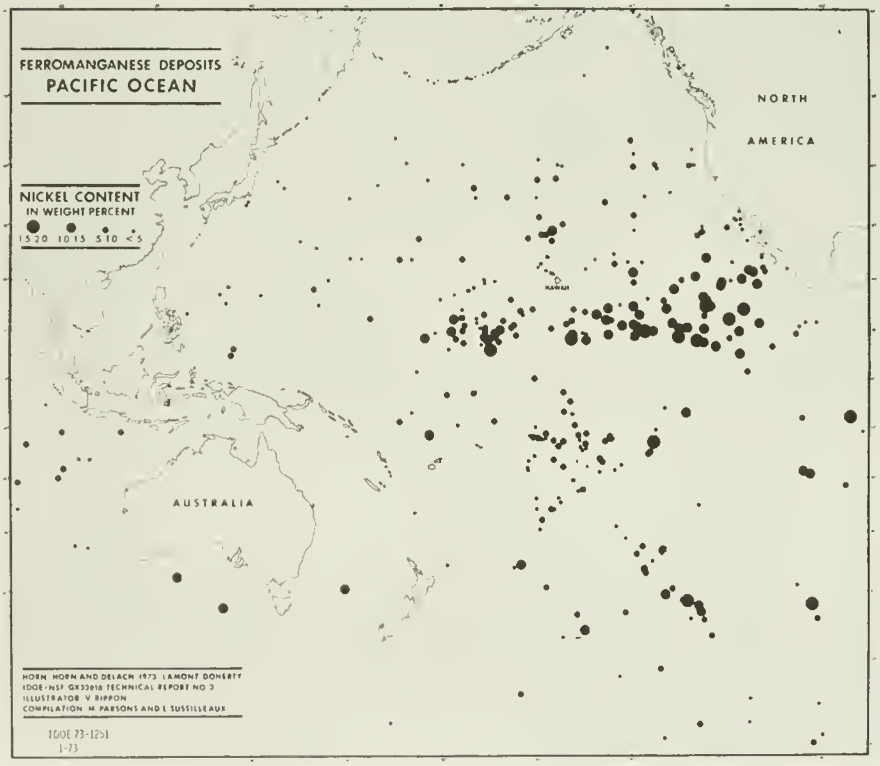


Figure 21b

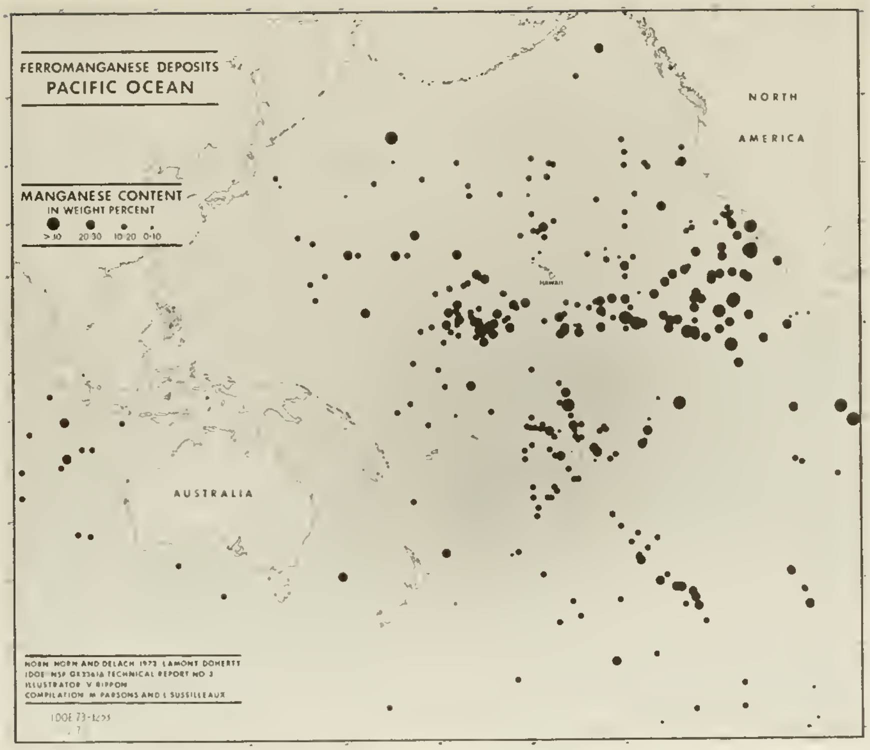

FERROMANGANESE DEPOSITS
PACIFIC OCEAN
MANGANESE CONTENT
IN WEIGHT PERCENT
>30 20-30 10-20 0-10
NORTH
AMERICA
AUSTRALIA
ILLUSTRATOR V RIPPON
COMPILATION M PARSONS AND L SUSSILLEAUX
IDOE 73-1255

Figure 21c

LIVING RESOURCES

MISSION:

Knowledge necessary for the intelligent use and management of living marine resources will come increasingly from interdisciplinary study of the mechanisms which produce and sustain marine life. The goal of the Living Resources Program, which in 1971 became the fourth IDOE program area, is improved understanding of the processes and relationships that exist between the biological aspects of marine organisms and the chemical, physical and geological environment in which they live.

The ocean can provide a large amount of food, but the quantities which can be harvested on a sustained basis are limited. Thus, the optimal use of renewable marine resources depends on knowledge of the natural productivity of the seas, regional differences, efficiencies of energy transfer from photosynthetic plants to harvested species and the population dynamics and maximum sustainable yield of different species. Until more is understood about the influence of temperature, currents, pollutants and weather on marine life, sensible decisions about the management of these resources will not be possible.

PROGRAM:

COASTAL UPWELLING ECOSYSTEMS ANALYSIS (CUEA)

Currently, the Living Resources Program is concentrating on marine ecosystems analysis. Scientists from a variety of disciplines and institutions are trying to unravel the interrelationships of marine organisms and their environments, and to generate models capable of predicting trends and changes in these relationships. The first such project is the Coastal Upwelling Ecosystems Analysis (CUEA). The primary objective of CUEA is to understand the coastal upwelling ecosystem so that responses of the system to change may be predicted from monitoring a few key biological, oceanographic and/or meteorological variables.

Concept

The upwelling phenomenon is significant because an estimated 50% of the world's fish supply comes from major upwelling areas. Upwelling usually occurs along the continental west coasts at low to mid-latitudes. When favorable winds exist, blowing toward the equator, the earth's rotation produces an offshore, or Eckman, drift of the upper ocean layers along the coast (Figure 22). This drift, in turn, produces an upwelling of colder, deeper waters near the coast, often a narrow band 10 to 15 km wide. The rich nutrients of the upwelled deeper water cause a rapid growth in the plankton population, upon which, in turn, fish feed. Upwelling is the key to the extremely high fish concentrations found off of Africa, South America and other major coastal upwelling areas (Figure 23).

Determination of the upwelling system variables hinges on joint physical and biological oceanographic investigations. The framework within which these investigations are to take place is a general ecosystems model (Figure 24). Data collection and experiments are guided by distinctive sub-models which make up the more general systems model. Each CUEA program scientist, as part of his own research effort, will contribute to building one or more of these sub-models which will be tested and modified continually to conform to new data obtained at sea. This elaboration of the sub-models as new data are obtained will help

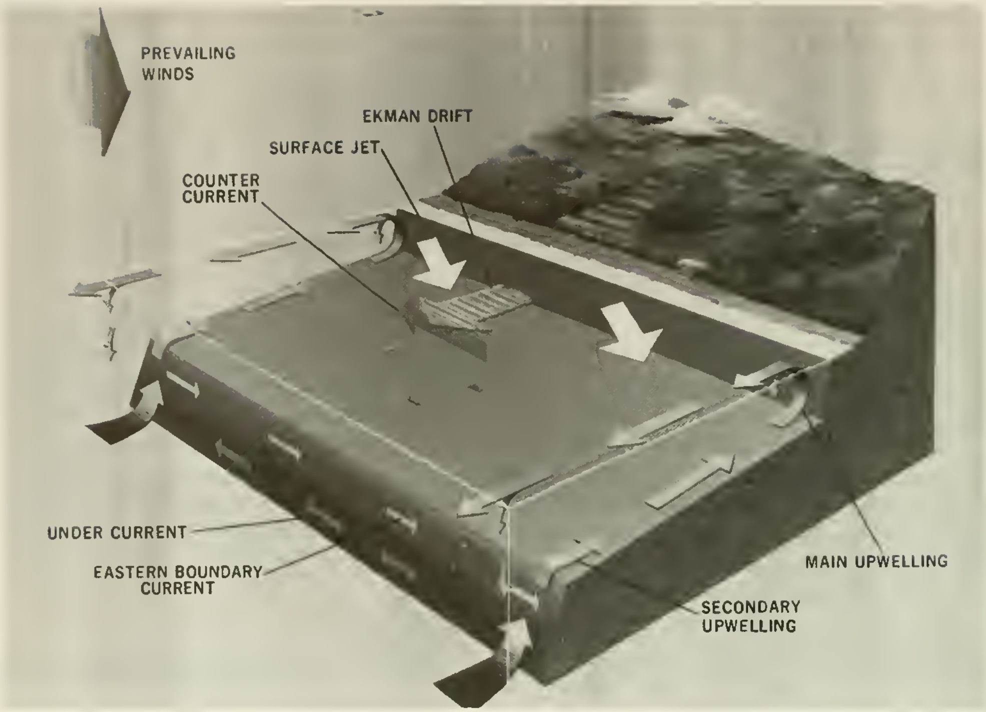


Figure 22

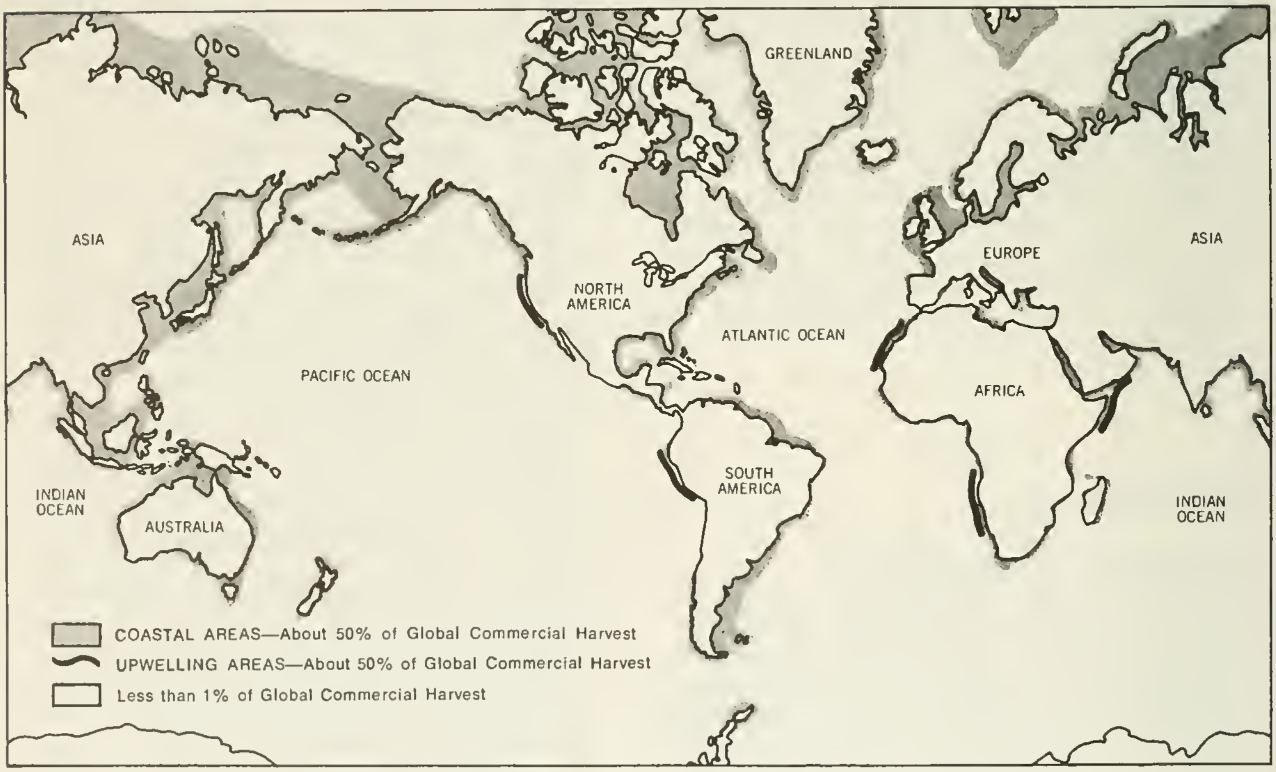


Figure 23 Distribution of the world's fisheries. The richness and importance of the global coastal areas are highlighted by a small number of intensely productive areas caused by upwelling.

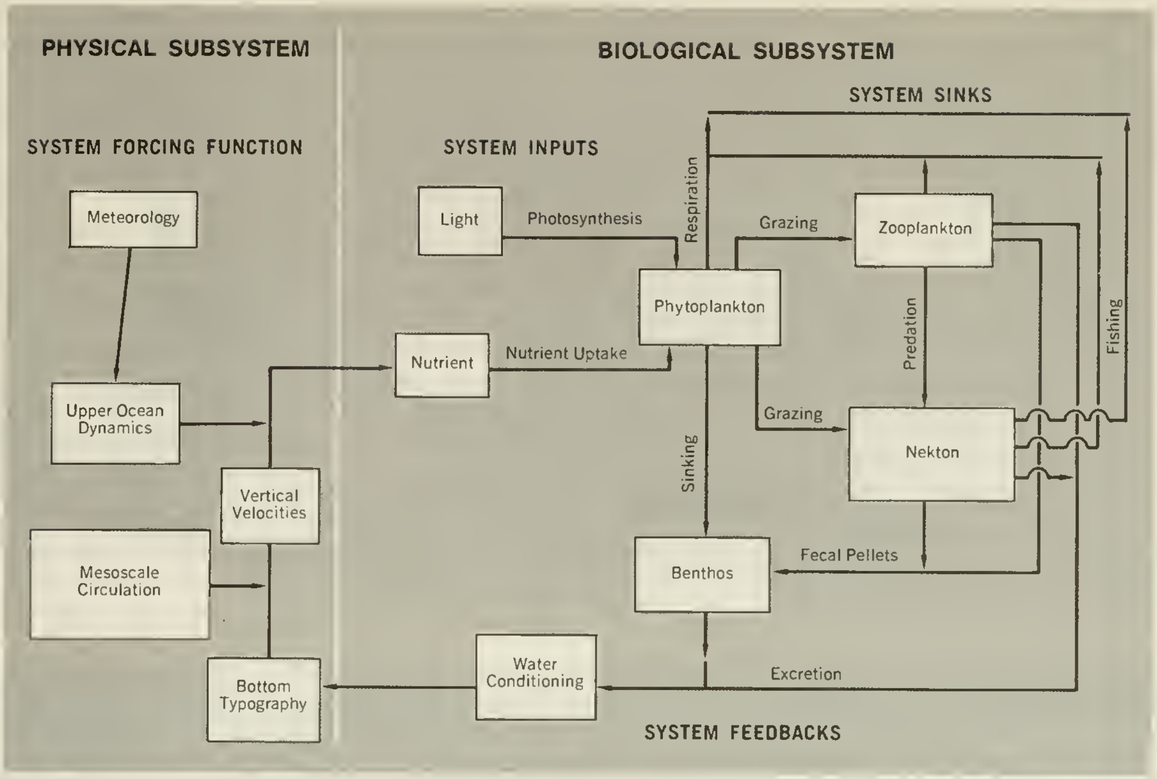


Figure 24 Conceptual model of the upwelling ecosystem, suggesting the relationship between the biological and physical parts of the system.

refine the field study design and generate increasingly accurate predictions about the behavior of the upwelling system.

The biological goals of the program are parallel to those of the physical oceanographic program components—i.e., to understand the production processes and their temporal and spatial scales. The approach is the same as that of the program in general. First, the important biological variables in time and space must be defined—especially those of the nutrients and phytoplankton. Naturally, there is interest in the fields of organisms at higher trophic levels, but the prediction of fish populations, for example, is not an initial project goal. The prediction of the fields of phytoplankton is, however, a fundamental aspect of the biological system and is an early goal of the project. Second, experiments must be carried out to determine the nature of the dominant processes and their rates. Third, the first two aspects must be combined in a biological systems model. Finally, the physical and biological models must be combined in a total ecological systems model.

Procedures and Equipment

The general field work design begins with locating the strongest upwelling areas. Automated shipboard equipment makes it possible to collect water continuously at 3 m and throughout the upper levels of the water column to 100 m. While the ship follows a zig-zag course in the upwelling area, the surface water can be sampled, and the variables of interest determined. This surface mapping can be done at night, and regular oceanographic or productivity stations can be occupied during the day to provide water for the biological processes experiments. During surface mapping, water enters a sea chest where *in situ* determinations of temperature and salinity are made. The water then flows to the ship's lab where nutrient and fluorescent determinations are done. The measurements are recorded by a shipboard computer, and surface maps of the variables can be produced as graphic output.

Intensive onboard experimentation and implantment of the oceanographic buoy arrays

follows the choice of the appropriate upwelling site. Contour maps are produced from the data which describe the field of the variables measured. Multivariant analyses are also possible from these data, but up until now a severe limitation to understanding the total field was imposed because the data were only two-dimensional.

The Underway Pumping System—The project now has an improved pumping system which enables continuous sampling in the vertical dimension as well as from the surface water (Figure 25). The pumping system consists of a towed body (fish) complete with pump and sensors, jacketed conducting cable and hose, and a launch and retrieval reel. The sensors read salinity, temperature and depth. The pump provides water for shipboard analysis of nutrients and fluorescence. The fish can operate at any depth down to 100 meters (the bottom of the euphotic zone in the eutrophic regions) and is controlled from the ship by manual or automated signals. The maximum towing speed is 14 knots, and the normal speed is 10 knots. Data from the towed fish make it possible to describe the vertical, as well as the horizontal, fields of measured variables. The vertical field description would otherwise have to be interpreted from bottle casts, which supply fewer data.

CUEA Computing System—The study of ecosystem dynamics requires a highly responsive technological capability. Typical of the commitment of the CUEA program to responsive and flexible technology is the shipboard computing system (Figure 26), the Interactive Real-Time Information System (IRIS), which represents an innovative advance in oceanographic research.

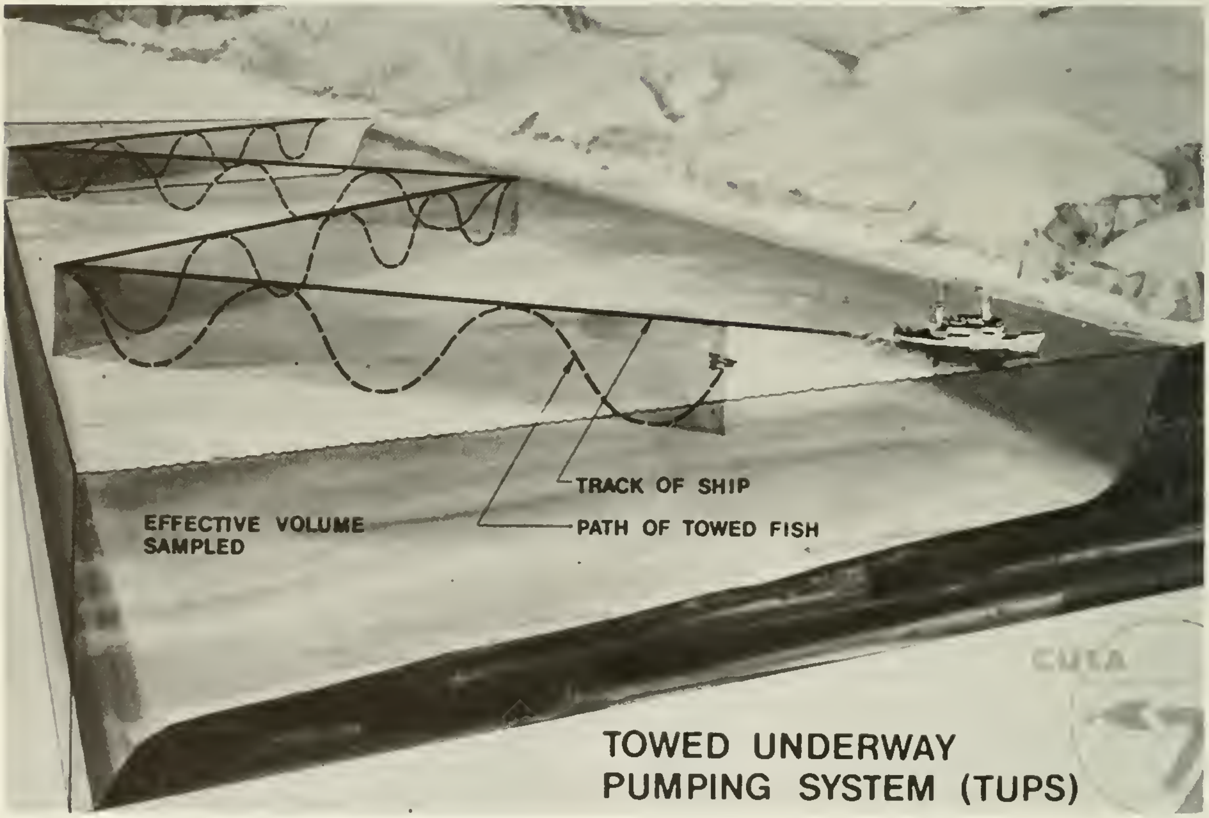


Figure 25 The Towed Underway Pumping System (TUPS) will provide continuous data in real time from any depth up to 100 meters with the ship underway at up to 12 knots. Together with the continuous surface sampling system, TUPS will allow CUEA scientists to define the three-dimensional fields of important variables such as temperatures, chlorophyll and the nutrients.

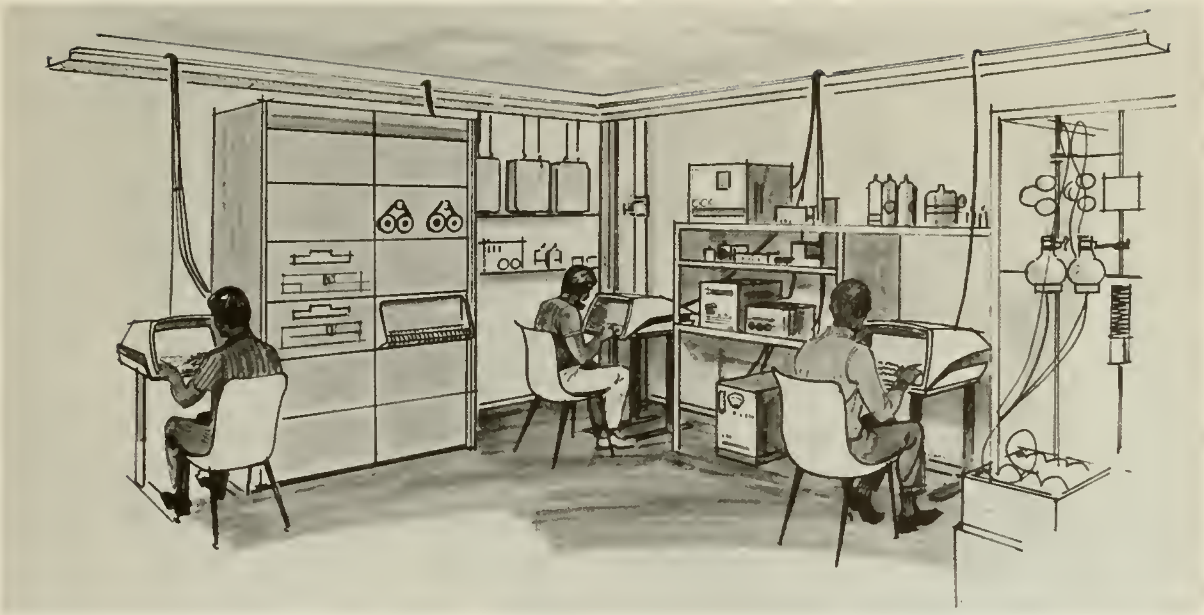


Figure 26 The CUEA shipboard computing system. Schematic view of the CUEA Van based modular computer and graphics system. This Interactive Real-Time Information System (IRIS) is transportable and will be installed in a van which can be placed on the deck of the ship. The central computer is connected to a peripheral processor in the ship's lab by means of a single cable. In the lab, the peripheral processor samples data in real-time, for example the under-way nutrients, and provides a facility for the investigators to interact at graphic terminals with the data contained in the central computer.

IRIS provides the scientist at sea with as clear a representation as possible of surrounding oceanic conditions. It acquires data in real-time from an instrument array, constructs an image of the real-time environmental conditions from these data and graphically presents the image. The scientist is able to manipulate the graphic images, perform statistical or analytical calculations on the data and store the results in a personal disk file. The instrument array includes sensors for continuous collection of data on nutrient chemistry, other water properties and relevant meteorological measurements. Data such as reversing-thermometer readings, and others which require high-precision analyses but are not amenable to continuous *in situ* measurement are placed directly into the IRIS from remote terminals. All these data and those collected by sophisticated stand-alone instruments, such as recording current meters and acoustic biomass assessment systems, are stored in the IRIS data files.

IRIS provides both an information center and a data-acquisition system for the CUEA field experiments. To perform these two functions, IRIS is configured with dual processors—two Digital Equipment Corporation PDP-11/45 computers—communicating over a high-speed link. One processor, the major storage devices and peripherals are mounted on the deck in a sea-transport van (Figure 27). The second processor, mounted in the ship's laboratory area, functions as a data acquisition facility and as a handler for the interactive graphics terminals. Data acquired by the inboard processor is transmitted to the van-based processor for entry into the data bank. The inboard processor also uses these data to construct a real-time representation of environmental conditions for investigators at terminals by the inboard processor. IRIS, transportable in a single van, provides a highly sophisticated information system for the CUEA program.

Experiments

The foundation for the CUEA program has been established by the work of more than twenty physical and biological oceanograph-

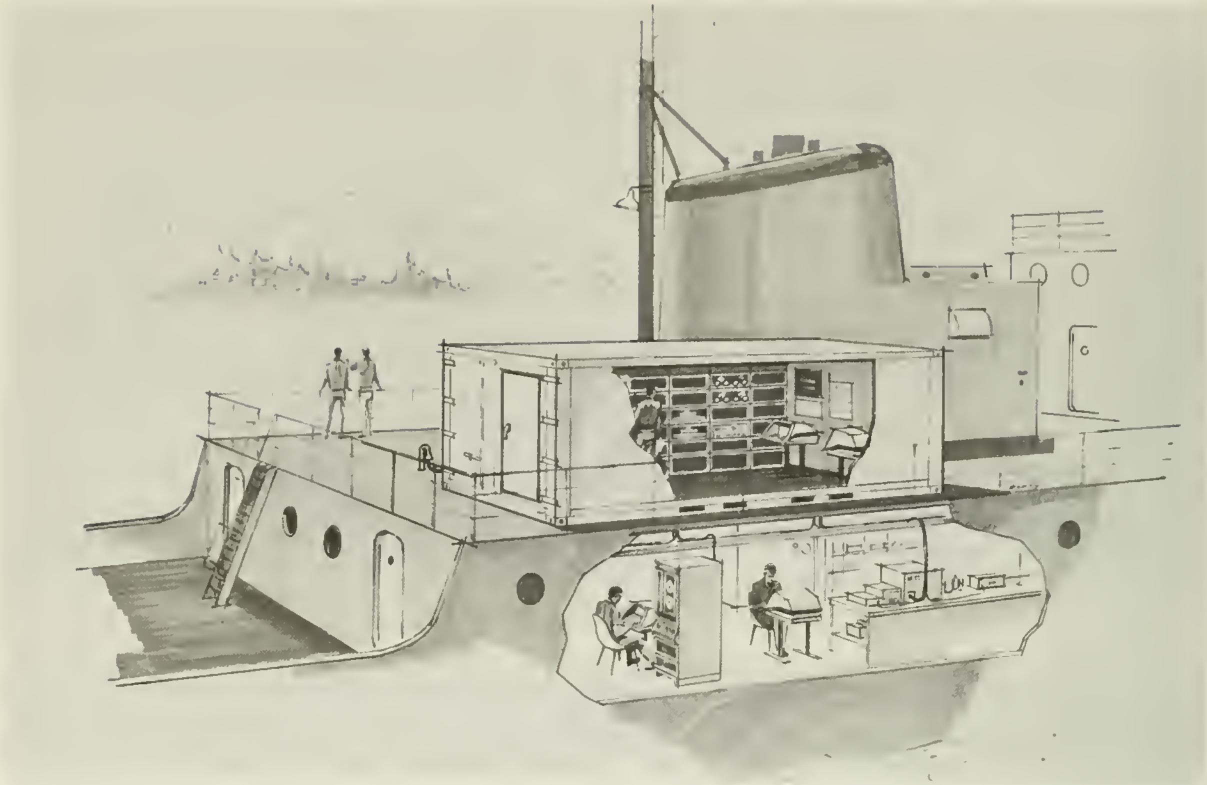


Figure 27 Cutaway view of a sea-transport van and peripheral lab area installation CUEA shipboard computing system.

ers from fourteen organizations. Four preparatory field experiments, MESCAL-I and -II and CUE-I and -II (Figure 28), precede the major combined biological and physical oceanographic effort (JOINT-I) planned off northwest Africa for 1974.

MESCAL—MESCAL-I was conducted primarily as a biological cruise off Baja California in March 1972. It was designed to obtain time series measurements on environmental variables such as temperature, nitrogen, chlorophyll and silicon, and to examine associated biological processes in the developmental stages of an upwelling system. During MESCAL-I, scientists observed a feature which appears typical of upwelling areas over complex topography. The feature, called a plume, appears as a surface tongue of water—in this case, a tongue of low-temperature, nutrient-rich water. It is hypothesized that the biological activity associated with upwelling plumes is a key factor in upwelling-system dynamics.

Early analysis of data collected during MESCAL-I indicates that prediction of phytoplankton levels and nutrient fields is possible. MESCAL-II, which took place in the same area during March and April 1973, further refined the phytoplankton-nutrients field model and integrated biological variables into the field work.

CUE—Upwelling off the Oregon coast is driven by seasonal north winds and occurs annually from May to September. During the summer of 1972, the first Coastal Upwelling Experiment (CUE-I) was carried out in this area. The goals were to define the time and space scales of the upwelling process, to test theoretical hypotheses and models and to test experimental hardware and techniques for future studies of upwelling ecosystems (Figure 29). CUE-I marked the first time that adequate experimental data were available to test the theoretical calculations and models. Although the results generally agreed with the models, additional information appears neces-

Figure 28 Geographical location of MESCAL and CUE experiments.

sary to deal with bottom contours and offshore upwelling frontal dynamics.

The CUE-I data collection effort was impressive. Continuous current measurements were made from three types of buoy arrays set up by Oregon State University, the Pacific Oceanographic Laboratory (NOAA) and the General Dynamics Corporation. Each buoy supported a current meter array and instruments to measure wind, temperature, salinity and other parameters. Surface and subsurface drogues were used to track short-term current variations, and several shoreside meteorological stations monitored the wind field just onshore. An aircraft, supplied by the National Center for Atmospheric Research, was used for rapid remote measurements of sea-surface temperature, color and flight-level winds. Earth satellite photographs and other weather summaries for the CUE-I area were collected and evaluated within the experimental model.

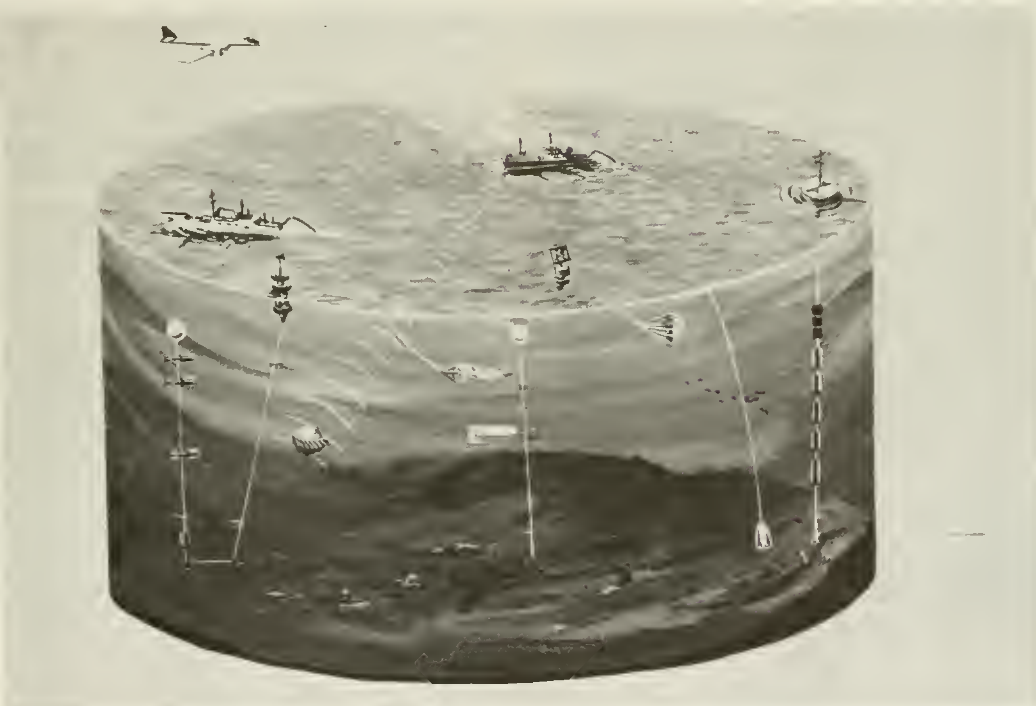


Figure 29 CUE-I instrument array. Some of the advanced technological development used in the 1972 physical-meteorological experiment off the Oregon Coast are shown above. From the left are: two point subsurface mooring of temperature, pressure & current meters with surface meteorological buoy, acoustically tracked. Neutrally buoyant Vertical Current Meter, subsurface mooring for Unattended Profiling Current Meter (also recording temperature pressure and salinity), surface drogue, Salinity-temperature-Depth recorder, telemetering buoy with temperature & pressure sensors. The National Center for Atmospheric Research aircraft on remote sensing flight is shown at top left.

Three ships, the *Yaquina* and *Cayuse* (Oregon State University) and the *Oceanographer* (NOAA), made over 1700 automated salinity, temperature and density measurements of the water column. More than 2000 current-meter days of circulation data were obtained. Intense computer processing of these data continued into early 1973.

Results of CUE-I have shown the time-motion scales of the coastal upwelling process. In addition to the seasonal scale of coastal upwelling, there are usually two or three short-term events per month which appear to profoundly affect the local upwelling circulation. The events, caused by a short-term shift to southerly winds (in the Northern Hemisphere), seem to stop the upwelling circulation and to stratify the coastal waters horizontally within a matter of a few inertial periods. The upwelling starts again with the resumption of the prevailing northerlies.

When the circulation observed during CUE-I turned out to be more complicated than anticipated, researchers decided to locate CUE-II north of the CUE-I location in an area of smoother bottom contours. Emphasis was on increasing the data base and testing physical theories derived from CUE-I. CUE-II also provided an opportunity for a pilot test of IRIS to be mounted on the University of Washington's *R/V Thomas B. Thompson*. Data from CUE-I and -II should provide the descriptive and theoretical basis for the JOINT-I experiment, scheduled to take place off the northwest African coast in early 1974 (Figure 30).

JOINT-I—This experiment will be the first full-scale integrated experiment to be conducted on a marine ecosystem. The selection of the northwest coast of Africa is based on the presence of a powerful upwelling system in that region and the extensive scientific foundation provided by the Intergovernmental Oceanographic Commission-sponsored Cooperative Investigations of the Northern Part of the Eastern Central Atlantic (CINECA) program. More than twenty cruises by oceanographic and fisheries research vessels of eight countries have been conducted in the CINECA region to date, and an intensive multi-ship effort is taking place in 1973. The 1973 program, the first of two related CINECA phases, is primarily devoted to a detailed physical, chemical and biological assessment of the dynamics of the Canary Current and the coastal upwelling system. A possible link between those systems will also be investigated during transects from the coast to 550 km offshore. United States scientists from the CUEA project have taken part in seven cooperative cruises in this area and will lead the second major CINECA phase on upwelling process studies during 1974. The JOINT-I experiment will be a major attempt to understand each component of upwelling development: the offshore movement of surface water; surface water replacement by nutrient-rich waters from deeper, cooler layers; the growth of plants which feed on these nutrients; the growth of microscopic animals which feed on the plants; and, finally, the influx and growth of fish which feed on these smaller organisms. Present plans call for participation in JOINT-I by the United States, France, Spain and the Federal Republic of Germany. At least six ships are expected to contribute, including three from the U.S. and three from other participants. Largely as a result of this broad international participation, JOINT-I will be the first field experiment on a big enough scale to produce the data necessary for a working model of a complete upwelling ecosystem. Additional JOINT experiments are planned for subsequent years to further refine theory and modelling and to test the models on different upwelling ecosystems in different parts of the world. JOINT-II, for example, is proposed for 1975 in the Peruvian upwelling region.

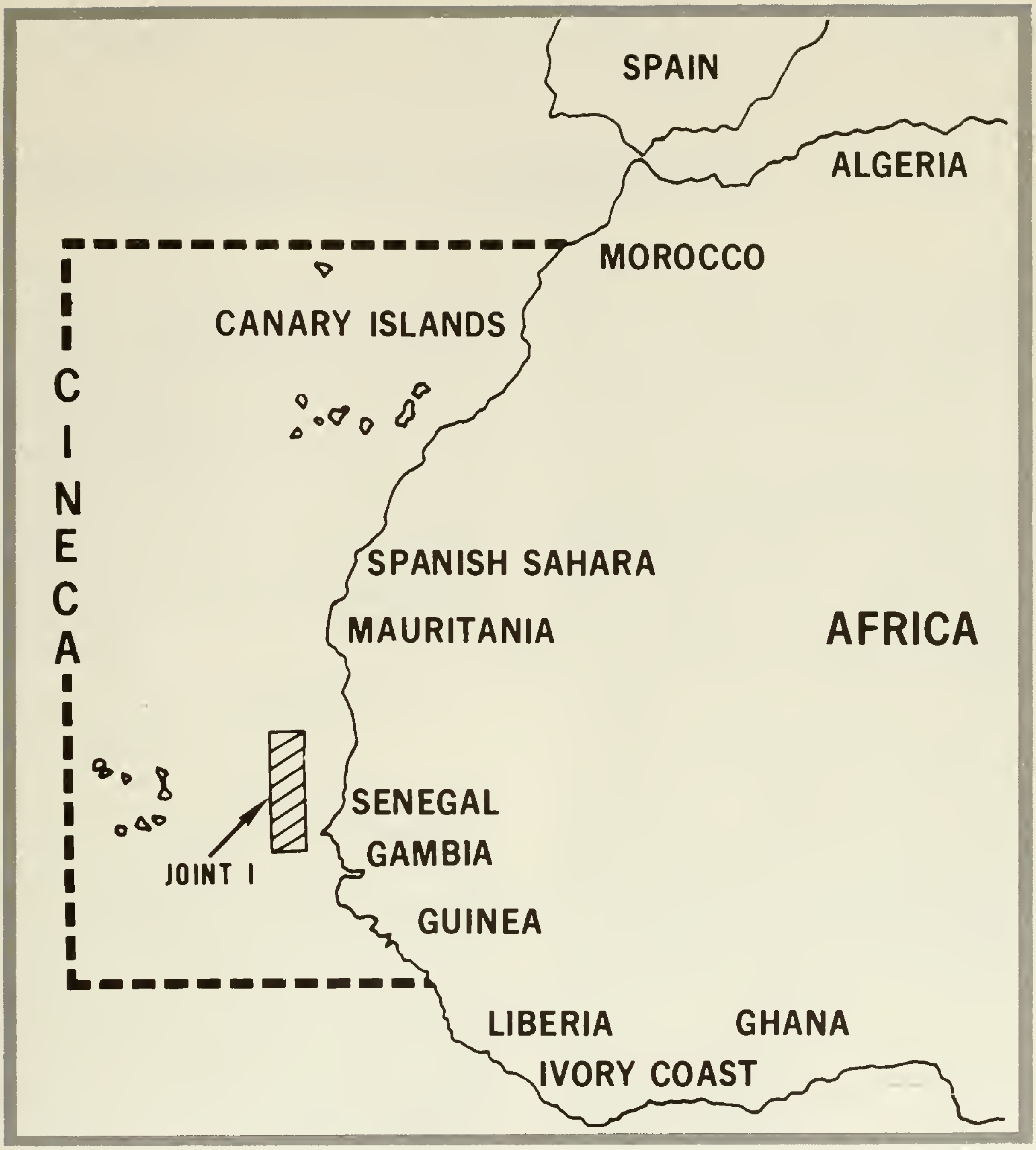


Figure 30 Location of the JOINT-I experiment.

Chapter 6

INTERNATIONAL COOPERATION

The success of the global IDOE program depends in large part on the extent to which many nations contribute their expertise and capabilities. The U.S. National Science Foundation has taken a leading role in working to develop scientifically sound cooperative programs offering opportunities for many nations to share both program responsibilities and results. The strength of existing projects stems from the participation of scientists from many countries. The Foundation has sought to foster this development in three ways: scientist-to-scientist cooperation, intergovernmental coordination and international scientific conferences.

SCIENTIST-TO-SCIENTIST COOPERATION

Convinced that scientific soundness is a prerequisite to viable international research projects, the U.S. IDOE Office contacted individual scientists from a number of countries during late 1969 and 1970, and invited them to assist in the planning of specific projects—a practice followed to this day. These specialists not only helped considerably in the planning, but subsequently encouraged participation by many foreign oceanographic institutions. By 1971 institutions in six foreign countries had committed resources, and scientists from nine other countries were taking part in various IDOE programs. A year later institutions in fifteen foreign countries had committed resources, and scientists from an additional fifteen countries were participating individually. By 1973, 41 countries were active participants in one or more U.S. IDOE projects (Table 3).

Specific examples of cooperative efforts developed through scientist-to-scientist cooperation are the Geochemical Oceans Section Study (GEOSECS), continental margin studies and research on plate tectonics and metallogenesis. The Federal Republic of Germany, France, the United Kingdom, India, Italy and Japan have participated extensively in GEOSECS with ships, personnel and laboratory facilities.

During the first year of the Eastern South Atlantic Continental Margin survey, participants came from Argentina, Brazil, the Republic of the Congo, the United Kingdom, the Federal Republic of Germany, France, Gabon, Ghana, Jamaica, Liberia, Nigeria, Portugal, Sierra Leone, South Africa, Spain and the United States. The Western South Atlantic continental margin survey is also underway with very active international scientific participation.

Scientists from three U.S. laboratories, five Latin American countries and the Pan American Institute of Geography and History are cooperating in the Nazca lithospheric plate project off the west coast of South America. Latin American scientists participated in all the initial cruises, and four worked in the United States on the data reduction and analysis. The planning for the 1973 research phase was a cooperative effort, as were the cruises themselves.

INTERGOVERNMENTAL COORDINATION

In addition to encouraging participation by individual foreign institutions and researchers, the United States has pressed for extensive internationalization of the IDOE through the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The IOC, established in 1960, now has seventy-four members (Table 4).

TABLE 3
Countries Cooperating in U.S. IDOE Projects

PROJECT / COUNTRY	GEOSECS	MODE	NORPAX	CLIMAP	SE Atlantic Research Vessel	SE Atlantic Science	NAZCA	Mid-Atlantic Ridge	Manganese	CUEA	SW Atlantic	Transfers	CEPEX
Argentina						*					*		
Australia			*										
Bermuda												*	
Bolivia							*						
Brazil						*					*		
Canada	*		*					*		*			*
Chile							*						
Colombia							*						
Congo						*							
Denmark				*									
Ecuador							*						
France	*	*	*		*	*		*		*			
Gabon						*							
Germany	*	*	*	*	*				*	*			
Ghana						*							
Greece										*			
Iceland								*					
India	*												
Israel						*							
Italy	*												
Ivory Coast										*			
Jamaica						*							
Japan	*		*							*			
Liberia						*							
Mexico										*			
Morocco										*			
Netherlands				*				*					
New Zealand									*				
Nigeria						*							
Norway				*						*			
Peru							*						
Portugal						*		*					
Senegal						*				*			
Sierra Leone						*							
South Africa					*	*							
Spain						*				*			
Sweden		*											
Switzerland				*									
Taiwan			*										
United Kingdom	*	*	*	*		*		*		*		*	*
USSR		*								*			

Table 4
IOC MEMBER STATES

Algeria	India	Philippines
Argentina	Indonesia	Poland
Australia	Iraq	Portugal
Austria	Israel	Romania
Belgium	Italy	Senegal
Brazil	Ivory Coast	Singapore
Bulgaria	Jamaica	South Africa
Cameroon	Japan	Spain
Canada	Kenya	Sweden
Chile	Korea (Republic of)	Switzerland
China (People's Republic of)	Lebanon	Syria
Colombia	Madagascar	Tanzania
Congo (People's Republic of the)	Malaysia	Thailand
Cuba	Malta	Trinidad and Tobago
Denmark	Mauritania	Tunisia
Dominican Republic	Mauritius	Turkey
Ecuador	Mexico	Ukrainian S.S.R.
Egypt	Monaco	Union of Soviet Socialist Republics
Finland	Morocco	United Kingdom
France	Netherlands	United States of America
Germany (Federal Republic of)	New Zealand	Uruguay
Ghana	Norway	Venezuela
Greece	Pakistan	Viet-Nam (Republic of)
Guatemala	Panama	Yugoslavia
Iceland	Peru	

The Seventh Session of the IOC in 1971 established the Global Investigation of Pollution in the Marine Environment (GIPME) as a major element of the IDOE, and the IOC Executive Council subsequently established the International Coordination Group for GIPME. The group is to draw on a variety of recommendations, such as those of the Joint Working Party on GIPME and those from the Stockholm Conference on the Human Environment, to prepare a comprehensive plan for implementation of GIPME. This plan is to include specific recommendations for long-term coordination and establishment of project priorities. The Coordination Group consists of representatives from Brazil, France, the Federal Republic of Germany, Japan, the Soviet Union, the United Kingdom and the United States, as well as six scientific experts —one from each of the following specialized organizations of the United Nations system: Food and Agriculture Organization, International Atomic Energy Agency, Intergovernmental Maritime Consultative Organization, U.N. Educational, Scientific, and Cultural Organization, and the World Meteorological Organization. The first meeting was held in April 1973, in the United Kingdom. The Environmental Quality Program of the U.S. IDOE is the national focal point for United States participation in GIPME.

In summary, the IOC has recognized the IDOE as the acceleration phase of its long-term program; it has adopted a series of programs to be implemented under the IDOE; and it has established a formal mechanism for the coordination of GIPME. The United States has actively participated in supporting these developments as well as in encouraging other IOC member states to sponsor these or similar projects.

INTERNATIONAL SCIENTIFIC CONFERENCES

To promote collaborative planning of IDOE programs, the U.S. Office for the IDOE is providing a two-year planning grant to the IOC. The funds will be used to support workshops comprised of scientists who will review existing efforts and develop new IDOE programs. Before support is provided for a workshop, the Scientific Committee on Oceanic Research of the International Council of Scientific Unions will assist by offering advice and recommendations for appropriate participants.

GOALS AND DETERMINATIONS

The full and general realization that our planetary environment has limits is an event of recent times. Indeed, as a factor of considerable national and international concern, it has emerged only within the last five years. These limits manifest themselves in many ways. Some are dramatic, such as the energy crisis. Some are more subtle, such as the gradual accumulation of man-made pollutants in the farthest reaches of the world ocean. They also show themselves in the onset of domestic conflicts over the uses to which specific national resources shall be put—to mine or maintain pristine beauty, to clear-cut or let the forests stand, to dump untreated waste or pay more for everything we do or use. They are evident, too, in conflicts among nations over access to such resources and the emergence of politics as an increasing factor in decisions that previously were mainly economic.

Global limits may be viewed from two basic perspectives: (1) What the environment can do for us in the sense of providing the resources necessary for human existence; growth and development; and (2) what we can safely do to the environment without endangering our survival, derogating the quality of life and reducing our future options. In the first respect we are concerned with a global demand for food, fuels and minerals that is rising faster than the discovery and proof of resources. In the second respect we are concerned not only with quality of life and future options, but also with the continued viability of the natural plant and animal cycles from which mankind derives its food.

It is through increased knowledge of the planetary environment that (1) the limits themselves can be pushed back through the discovery of new sources of raw materials, fuels and food; and (2) more efficient use can be made of those resources available to us at any given point in time. It is to the development of just this kind of knowledge that the International Decade of Ocean Exploration is dedicated.

The establishment of oceanic environmental baselines and the effects of environmental factors—both natural and man-made—on the biomass give us a standard against which we can measure and evaluate releases of pollutants, thus providing us with sound bases for avoiding major adverse impacts and for intelligent, balanced regulation. Through the study of marine ecosystems, we develop knowledge which not only permits fisheries harvest management within the limits of maximum sustainable yield and, therefore, assurance of continuing supplies, but also ecosystem enhancement and simulation—e.g., expansion of natural stocks and the creation of whole new stocks through mariculture. These are the kinds of questions to which IDOE's Environmental Quality and Living Resources programs seek answers which, in turn, serve the needs both of science and of men and nations.

Knowing more about the patterns of energy transfer within the ocean, within the atmosphere and between the two already enables us to make more accurate weather predictions over longer periods of time and over broader areas. This is important not only to protection of life and property, but it is also important to the more efficient use of resources, both human and material. If the farmer knows the next growing season will be cold or hot, dry or wet, early or late, he can plan and plant accordingly, and a whole new dimension can be added to the technology of modern agriculture, with concomitant increases of both nutritional and economic yield. To whatever extent the construction industry knows the weather in the next few days, weeks or months, greater economic efficiency is again realized. Similar benefits accrue to the fuels industry, states and municipalities, resort areas, transportation companies, indeed, to every individual and segment of the economy. Thus, while investigators of the MODE, NORPAX and CLIMAP programs are pursuing lines of purely scientific inquiry, they are also developing knowledge of immediate practical benefit to the whole of human society.

Recent rapid and exciting strides in marine geology—the whole field of plate tectonics, seafloor spreading and continental drift—have

already pointed the way to more efficient exploration by the petroleum industry. Similar benefits are now becoming available to the hard minerals industry. The ways in which the lithospheric plates of the earth's crust form, move, collide, disappear and interact are telling us for the first time how the important mineral deposits we find ashore are created. Knowing this mechanism—the processes and time scales involved—not only expedites the landside search for new mineral resources, but it is beginning to describe the mineral resources of an area three times that of the continental land masses on which, to date, we have primarily relied for such resources. That area, of course, is the ocean floor, the description and dynamic understanding of which is the main objective of the IDOE Seabed Assessment program.

One of the more intriguing aspects of this line of inquiry is the evolving evidence that the earth's hard mineral resources are constantly being renewed—not only through the rift valleys that characterize most of the 46,000 nautical miles of mid-oceanic ridges, but also along the island arc and other volcanic regions where lithospheric plates collide. No suggestion is made or even implied that the rate of such hard minerals creation in any way matches the rate at which modern industry is drawing them down. The possibility, if not the probability, exists, however, that rich deposits will be found beneath the deep ocean floor all the way from the rift/ridge structures that produce them to the continental boundaries. If this is so, planetary limits are still not removed, but they may be much expanded. Once again the quest for scientific knowledge produces an effect of universal, very practical importance.

The temporal benefits that soon may accrue from the discovery of manganese nodules by *H.M.S. Challenger* will have taken 100 years or more to be realized. The time scale from basic scientific discovery in marine research to practical utilization today is greatly foreshortened, and the pragmatic benefits of plate tectonics research are being realized within decades of initial hypotheses and within a very few years of actual scientific confirmation. Through IDOE's broad international participation, concerted multi-disciplinary efforts addressed to single major scientific problems and the availability of modern computer and numerical modeling technology, such short-term pay-offs are being realized or anticipated for every major IDOE program. Indeed, if there is a problem in the realization of practical benefits from these programs (e.g., Seabed Assessment), it is that currently the pace of oceanographic discovery with the potential to serve critical current needs is outpacing the technological capability to exploit. And, the natural pressure of the marketplace are beginning to solve that problem.

IDOE-supported oceanographic research seeks a level of understanding of natural processes that is functional rather than merely descriptive, that is quantitative as well as qualitative. We have already pretty well described the planet; now we strive to know how it works. We seek better to define its limits and to realize the fullest compatability between man, his needs and expectations and his environment and its resources.

The demands of most IDOE programs exceed the practical capabilities not only of individual institutions but often of individual nations. A sharing of effort among many institutions and nations is essential to bring together sufficient financial and other material resources. Since no single nation can reasonably undertake the development of such knowledge entirely on its own, it is only logical that there should be a common effort to fulfill critical common needs. This is the rationale behind the cooperative aspects of IDOE.

It is the goal of the IDOE to produce the knowledge that will provide the factual bases to enable man to optimize his compatability with his environment, to maximize the continued availability of food, fuels and raw materials and to minimize future sources of conflict both within and among nations. The least cost and shortest route to this goal is through the development of a truly energetic common assault on common problems.

APPENDIX

Table 1

Major U.S. IDOE Research Projects Initiated in FY 1971 and 1972

Project	Number of Institutions	Number of Scientific Investigators	Duration (years)	Estimated Total Cost (In Millions of Dollars)
NORPAX	4	9	10	30.0
CUEA	12	22	8	17.0
GEOSECS	14	28	7	16.0
POLLUTANT TRANSFER	6	7	8	10.0
CLIMAP	3	14	8	8.0
MODE I	10	19	4	6.5
NAZCA Plate	4	40	5	6.5
WEST AFRICA MARGIN	1	8	5	4.0
POLLUTANT BASELINES	17	30	7	2.3
CEPEX	4	8	6	6.0

Table 2

U.S. IDOE Funding, FY 1971 - FY 1973
(In millions of dollars)

	FY 71	FY 72	FY 73
Environmental Quality	2.2	5.8	5.0
Environmental Forecasting	7.0	8.7	5.9
Seabed Assessment	5.2	3.8	4.1
Living Resources	0.3	1.1	1.8
General Support	0.3	0.3	0.4
TOTAL	15.0	19.7	17.2

Table 3

U.S. IDOE PARTICIPANTS

ACADEMIC

University of Alaska
Brown University
California Institute of Technology
University of California San Diego
University of California Berkley
University of California Los Angeles
Columbia University
University of Connecticut
Duke University
Harvard University
University of Hawaii
University of Georgia (Skidaway)
Johns Hopkins University
Lamont-Doherty Geological Observatory
Massachusetts Institute of Technology
University of Miami
Nova University
Oregon State University
Puerto Rico Nuclear Center
Queens College
Rice University
University of Rhode Island
University of Southern California
Texas A & M University
University of Texas
Woods Hole Oceanographic Institution
Yale University

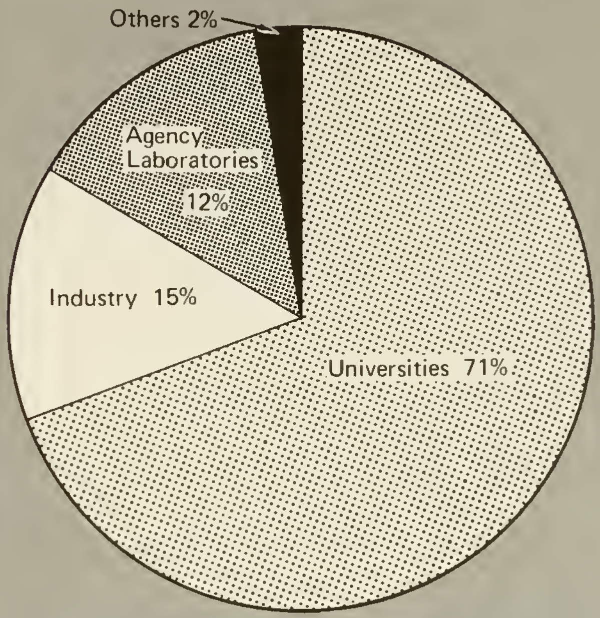
GOVERNMENTAL

Atomic Energy Commission
National Bureau of Standards
Atlantic Oceanographic and Meteorological Laboratories (NOAA)
Pacific Oceanographic Laboratory (NOAA)
National Marine Fisheries Service (NOAA)
Geophysical Fluid Dynamics Laboratory (NOAA)
Environmental Data Service (NOAA)
National Oceanographic Instrumentation Center (NOAA)

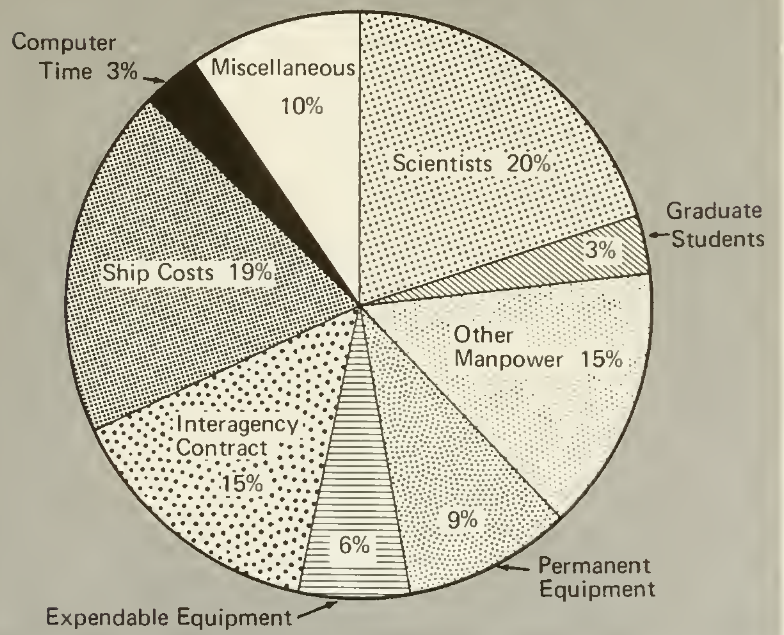
NON-PROFIT AND INDUSTRY

American National Standards Institute
Battelle Northwest
National Academy of Sciences
National Academy of Engineering
General Dynamics—Electronics Division

Percentage Distribution of Funds By Type of Performer



Percentage Distribution of Funds By Manpower and Other Factors



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